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REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-OM-3

USER'S MANUAL: INSPECTION AND RATING OF STEEL SHEET PILE STRUCTURES

by

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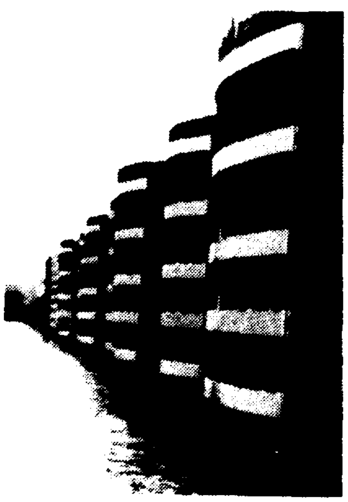

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GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP – Lock and Dam #17 on the Mississippi River at New Boston, IL. Upper transition wall under repair.

BOTTOM – Lock and Dam #3 on the Monongahela River. Intermediate lower guidewall.

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For much of its early history the U.S. Army Corps of Engineers was heavily involved in the design and construction of new facilities, but now the mission of the Corps is shifting from construction to the maintenance of existing facilities. The Corps has addressed its changing role by instituting a Repair, Evaluation, Maintenance, and Rehabilitation (REMR) program. As a part of this program, a project team at Iowa State University has undertaken a research effort that focuses on the evaluation and repair of the steel sheet pile structures within the Corps' civilian projects. These structures do not

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require a great deal of maintenance but failure of a steel sheet pile wall can significantly affect operations--especially as part of a lock and dam facility. Steel sheet pile structures provide an excellent vehicle around which a maintenance program can be developed, because the methodology developed for this relatively simple type of structure can be extended to more complex and critical structural systems. The specific objective of this initial work is to develop an inspection and rating system that uniformly and consistently describes the current condition of steel sheet pile structures.

During the past two years, the project team at Iowa State University has conducted several site visits and field investigations. Experts from the Corps of Engineers were asked to rate several walls and the results were compared to a preliminary version of the rating system. Modifications were made to reflect more accurately the experts' opinions. The inspection and rating system given here is now ready for wider distribution and additional feedback.

In the following document, a general description of the current inspection and rating system is given. This includes the definition of a condition index and a brief description of sheet pile distresses. A detailed description of the inspection process follows. Once the inspection data have been gathered, they are entered onto a computer disk through a personal computer (PC) program. The description provides sufficient detail for a trial application of the inspection process.

PREFACE

The study reported herein was authorized by Headquarters, U S Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit 32280, "Development of Uniform Evaluation for Procedures/Condition Index for Deteriorated Structures and Equipment," for which Mr. Anthony M. Kao is Principal Investigator. This work unit is part of the Concrete and Steel Structures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program sponsored by HQUSACE. Mr. Jim Crews (CECW-OM) is the REMR Technical Monitor for this work.

Mr. Jesse A. Pfeiffer, Jr. (CERD-C) is the REMR Coordinator at the Directorate of Research and Development, HQUSACE; Mr. Jim Crews and Dr. Tony C. Liu (CEEC-ED) serve as the REMR Overview Committee; Mr. William F. McCleese (CEWES-SC-A), U S Army Engineer Waterways Experiment Station, is the REMR Program Manager; Dr. Kao is also the Problem Area Leader for the Operations Management problem area.

The study was performed by the College of Engineering, Iowa State University, under contract to the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Principal Investigators for Iowa State University were Messrs. Lowell Greimann and James Stecker.

The study was conducted under the general supervision of Dr. R. Quattrone, Chief of the Engineering and Materials (EM) Division of USA-CERL, and under the direct supervision of Mr. Anthony M. Kao, EM, who was the Contracting Officer's Representative.

COL Carl O. Magnell was Commander and Director of USA-CERL and Dr. L. R. Shaffer was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees	0.0174533	radians
cubic feet (ft^3)	0.0283	cubic metres
feet	0.3048	metres
inches	25.4	millimetres
pounds (force)	4.448222	newtons
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	0.006894757	megapascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

USER'S MANUAL: INSPECTION AND RATING OF STEEL SHEET PILE STRUCTURES

PART I: INTRODUCTION

Background

1. The U S Army Corps of Engineers has acquired a large inventory of civilian work projects over the past 100 years. For much of this time the Corps was heavily involved in the design and construction of new facilities, such as locks and dams on the navigable inland waterways and coastal systems, and power generation. Recently, the mission of the Corps has been shifting from the construction of new facilities to the maintenance of existing facilities. Several factors have prompted this shift: many existing structures are nearing the end of their design life and fewer opportunities for expansion of Corps projects are available. The Corps has addressed its changing role by instituting a Repair, Evaluation, Maintenance, and Rehabilitation (REMR) program. As the name implies, there are several aspects to the general topic of maintenance. To some extent, each aspect requires the development of a new technology and methodology.

2. As a part of this program, a project team at Iowa State University has undertaken a research effort that focuses on the evaluation and repair of the steel sheet pile structures within the Corps' civilian projects. Steel sheet pile structures are certainly not the most critical items in a lock and dam facility. These structures, which have a long design life and are not a part of the operating machinery of the lock and dam facility, do not require a great deal of maintenance. On the other hand, failure of a steel sheet pile wall can significantly affect operations--especially as part of a lock and dam facility. As such, these structures provide an excellent vehicle around which a maintenance program can be developed. The methodology developed for this relatively simple type of structure can be extended to more complex and critical structural systems.

3. In the overall scheme of REMR, the steel sheet pile work will be coupled with studies on other components to describe the condition of the entire lock and dam facility. At least on a theoretical basis, the condition information can be fit with concepts of life-cycle costs (and many other factors) to assess priorities and to plan long-term maintenance.

Objectives

4. The objectives of this work are twofold:

   a. To develop a uniform procedure to describe the current condition of steel sheet pile structures.

   b. To develop guidelines for the repair of these structures.

These objectives are being accomplished over a period of several years. The focus of this users' guide is the first objective: to develop an inspection and rating system that uniformly and consistently describes the current condition of steel sheet pile structures. Work on the second objective has begun. A preliminary set of repair guidelines has been collected. It is premature to report on these suggestions until they have been more thoroughly reviewed by experts in the field.

Overview and Scope

5. During the past 2 years, several meetings have been held between Corps personnel, ISU personnel, and others. The project team at Iowa State University has conducted several site visits and field investigations. A field trip was conducted in the Chicago area in July, 1987. Experts from the Corps of Engineers were asked to rate nine walls. The results were compared to a preliminary version of the rating system and modifications were made to reflect more accurately the experts' opinion. In this users' guide, the current version of the inspection and rating system is described. The inspection and rating system is now ready for wider distribution. Feedback will be used to modify the system before final implementation.

6. In this report, a general description of the current inspection and rating system is first given. This includes the definition of a condition index and a brief description of sheet pile distresses. A detailed description of the inspection process follows. Once the inspection data have been gathered, they are entered onto a computer disk through a PC computer program. The description provides sufficient detail for a trial application of the inspection process. The calculation of the condition index is done within the computer program and will be printed out at the user's request. The scope of this project has been specifically limited to steel sheet pile structures associated with lock and dam facilities.

Mode of Technology Transfer

7. It is recommended that the inspection procedures developed in this study for steel sheet piles be incorporated into ER 1110-2-100, "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures."

PART II: OVERVIEW OF INSPECTION AND RATING PROCEDURES

8. A general overview of the inspection and rating procedures and background is presented in this section. Several details regarding the rating system are presented in the Appendixes.

Steel Sheet Pile Component Identification

9. To inspect and rate steel sheet pile structures, their functions and components must be clearly identified.

Functions

10. Lock Chamberwall--One of two long parallel walls that forms the lock chamber. The lock chamberwalls will generally extend just beyond the recesses for the lock gates (Figure 1).

11. Lock Guidewall--A wall used to guide barge traffic into and out of the lock; this wall begins at the end of the lock chamberwall. The guidewall may be upstream or downstream from the lock and on the land side or river side of the lock approach (Figure 1).

12. Transition Wall--A retaining wall used in the transition from the lock guide walls to the natural bank or levee (Figure 1).

13. Cutoff Wall--A wall used to retard the flow of water under a lock dam or other structure. The wall is usually completely buried and has no anchorage system.

14. Mooring Structure--A structure to which a barge is tied. The most common type is a steel sheet pile cell filled with concrete or coarse aggregate (Figure 2).

15. Protection Structure--A structure used to prevent damage from barge collisions to bridge piers, lock facilities, and the like. The most common type is a steel sheet pile cell filled with aggregate and covered with a concrete cap.

Components (Figure 3)

16. Steel Sheet Pile--Hot-rolled steel sections that may have a variety of shapes (Z, arch, straight) or method of interlock (thumb and finger, ball and socket). The sections are driven vertically into the soil. Each sheet

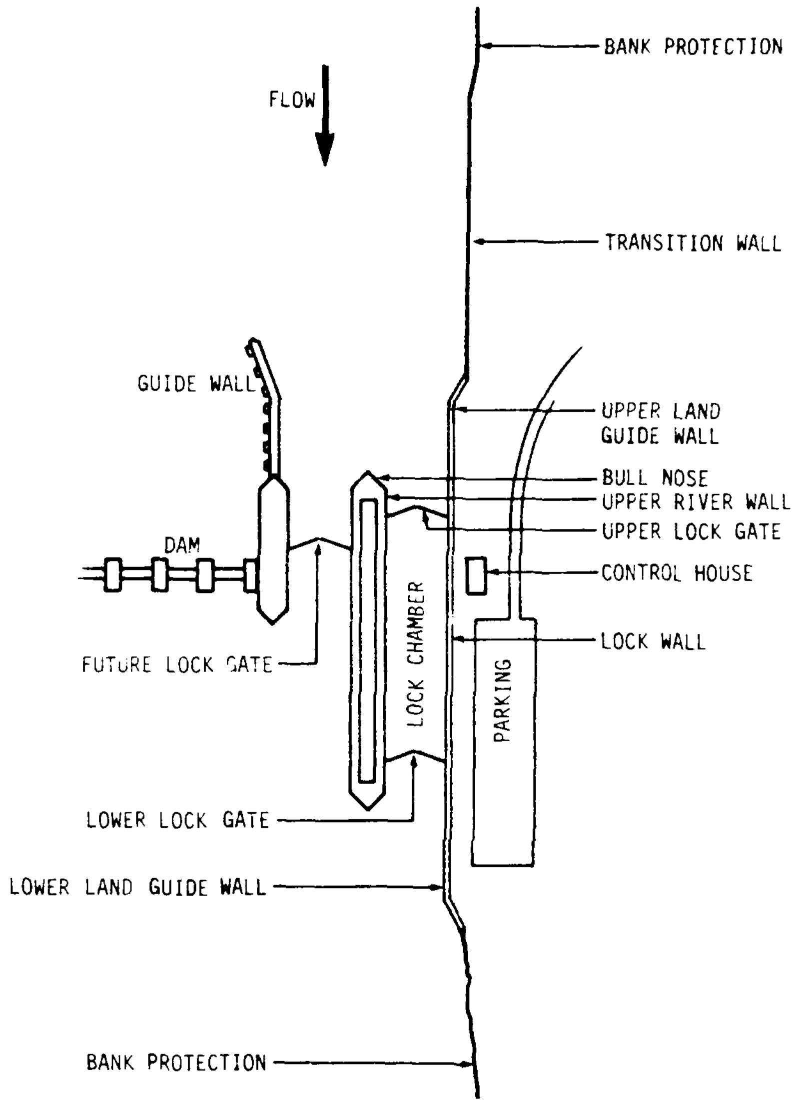


Figure 1. Lock and dam facility

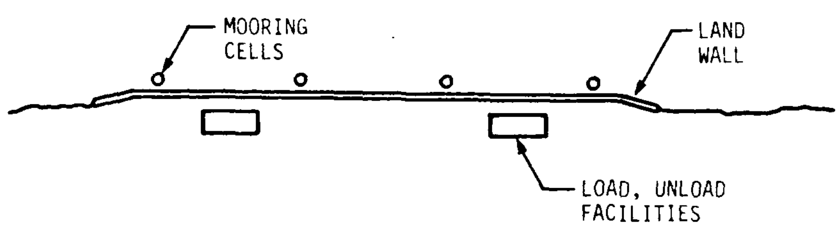


Figure 2. Terminal facility

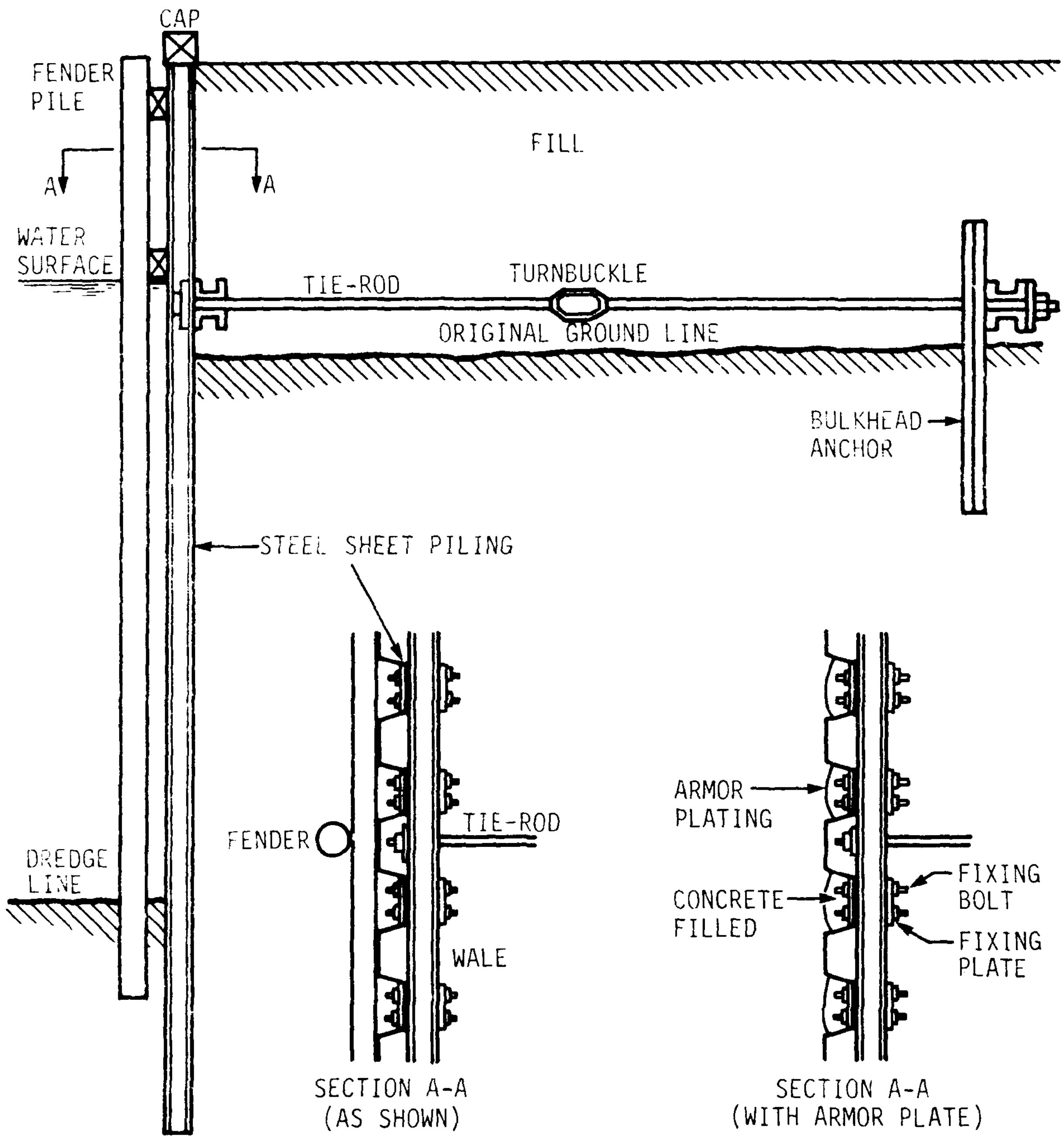


Figure 3. Typical components of steel sheet pile structures

is interlocked continuously from top to bottom with adjacent sheets. (See Appendix A.)

17. Wale--Rolled-steel section running horizontally along a steel sheet pile wall and used to transfer loads from the steel sheet pile wall to a tie-rod and anchor system. The wale generally consists of two channels back to back with 2 in. or 3 in. spacers. The sheets are often bolted to the wale.

18. Tie-Rod--Steel rod used to transfer loads from the wale to an anchor system. The rod is threaded at each end in order to bolt it to the wale and anchor it with a turnbuckle in between. The tie-rod is usually a 2 in. to 3 in. diameter rod. A steel cable may also be used.

19. Anchor--A structure that transmits the tie-rod loads to the soil. It may consist of a sheet pile wall and wale, a concrete block, or some battered pile and cap arrangement. A battered pile bolted directly to the wale may also be used for an anchor.

20. Cap--A wood, steel, or concrete structure placed on top of the sheet piles. A railing may be attached to the cap.

21. Fenders--Structures used to prevent damage to the piles from barges. These may be wood or steel and are usually bolted horizontally to the sheets above the water level.

22. Armor Plating--A curved steel section welded between flanges of Z piles to help protect the wall from barge collisions. The void is usually filled with concrete.

Structural Form

23. Cantilever Wall--Wall that resists active earth pressure, or water and/or ice forces as a vertical cantilever. The horizontal force and moment resistance are provided by the passive soil pressure on the embedded portion.

24. Anchored Wall--Wall that resists active earth pressure as a beam spanning between the passive soil pressure on the embedded portion and the anchor tie-rods near the top. (Figure 3).

25. Single Cells--A series of interconnected, straight-web steel sheet piles usually arranged in a circular plan shape. The interior is filled with soil, concrete, and/or stone. The structure resists the applied forces, for example, mooring and impact as well as wave and ice loads, principally by gravity and sliding forces.

26. Cellular Wall--A wall formed by interconnected cells. Figure 4 illustrates some of the possible plan views. A cellular wall resists forces in a manner similar to single cells.

Inspection Concepts

27. A basic idea behind the inspection procedure is simplicity. As meetings with Corps personnel progressed and field tests with Corps personnel confirmed, it became increasingly clear that any steel sheet pile inspection program must be simple to learn and not time-consuming. Two factors force this conclusion: Steel sheet pile structures are not the most critical item in a lock and dam facility and Corps personnel who work with lock and dam facilities generally feel they will have little time to devote to this work. Current inspection procedures ranged significantly between districts. No district that was involved in this pilot project now spends much time inspecting steel sheet pile structures. In districts where steel sheet pile is used for floodwalls or dams, the situation may be different.

28. With these restrictions, the field inspection had to be based on easily obtainable data. In this case, easily obtainable data were taken to be those that could be obtained by walking along the land side of the wall or boating along the water side. The normal inspection would involve no excavation or diving. No ultrasonic or other "sophisticated" devices could be used. All data would be measured by subjective observation (poor, average, good, excellent, etc.), a tape measure, a level, a string line, a camera, and the like. (Figure 5, p. 22, lists equipment requirements for each task.) As a goal, the data would be recorded by technicians with no particular engineering training or experience in the design or construction of steel sheet pile structures. Certain components such as the wale, anchor rod, and anchor system are not visible and hence cannot be part of this inspection.

29. The rating process generally follows this pattern:

a. Historical information, such as drawings and previous inspections, is reviewed and recorded before a site visit.

b. A site inspection is conducted and specific visual data are recorded.

c. The inspection data are entered into a personal computer (PC) program.

d. The steel sheet pile condition index is calculated.

The time period between inspections has not been established, but will probably be between 3 and 5 years.

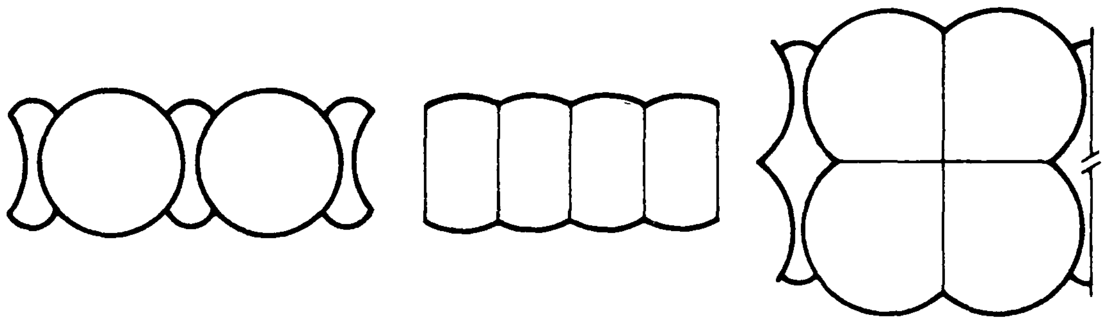


Figure 4. Cellular walls

30. The results of the inspection, for example, the condition index, are intended to be indicative only of the existing condition and must be viewed as such. As is pointed out above, the results are based only on visual information. For some cases, it may be necessary to return and conduct a more detailed inspection, for example, by excavation, diving, or surveying. This will clearly be the case if a dangerous condition is indicated by the initial inspection. It is beyond the scope of this portion of the project to describe a detailed inspection.

Condition Index

31. A condition index (CI) is a numerical measure of the current state of a structure. It is part of the objective of this project to define a condition index that uniformly and consistently describes and ranks the condition of steel sheet pile structures. The condition index is primarily a planning tool, with the index values serving as an indicator of the general condition level of the structure. The index is meant to focus management attention on those structures most likely to warrant immediate repair or further

evaluation. In addition, the CI values can be used to monitor general condition change over time and can serve as an approximate comparison of the condition of different structures.

32. During the many meetings and discussions that have been held on this subject, a common definition of condition index for the REMR work has evolved. The REMR Condition Index is a numbered scale, from a low of 0 to a high of 100. The numbers indicate the relative need to perform REMR work because of deterioration of the functional and safety characteristics of the structure. The condition index scale in Table 1 has been adopted. For management purposes, the condition index scale is calibrated to group structures into three basic categories or zones, as listed in Table 2.

Structural Condition Index

33. As this project progressed, two general criteria for evaluating the condition index of a structure evolved. First was the safety aspect. The safety of a structure relates to its performance beyond normal service conditions, for example, under abnormal conditions such as excessive load or unexpectedly poor soil conditions. Safety often refers to potential loss of life and/or significant property damage. If a structure is unsafe, it is in danger of collapse. Structural safety has traditionally been measured by a factor of safety. Hence, uncertainties in loading and structural strength, that is, abnormal conditions, are covered by selecting an appropriately high factor of safety to ensure a sufficient margin between the applied loads and the structural resistance. For example, the design criteria for steel sheet pile typically require a factor of safety of two. (See Appendix B.)

34. In this project a structural condition index is defined which is a measure of the safety of the structure or risk of failure of the structure. It is based directly on the factor of safety of the structure (Appendix B). The factor of safety calculation is often perceived as a fairly rational, objective process. This is so, in spite of the many simplifying assumptions that must be made. Presumably, the structural condition index would be reasonably repeatable if everyone was given the same beginning information.

Functional Condition Index

35. The second set of criteria that evolved were much more subjective. They involved "engineering judgment" and depended upon the experience of the

person making the evaluation. These aspects of the condition index were much more difficult to capture. Experts in this field were interviewed and discussions continued for some time until a consensus began to develop.

36. The experts took many factors into account as they evaluated the functional condition index. One aspect was the serviceability of the structure, that is, its performance at and below normal service conditions on a day-to-day basis. For example, if a lock wall is significantly out of alignment, the movement of barges through the lock will be affected. Aesthetics is also an aspect of serviceability. The appearance of the wall in its particular location is important.

37. Another factor involved in the functional condition index is, for lack of a better phrase, subjective safety. Subjective safety refers to the idea that an engineer, using his subjective engineering judgment, may decide that a safety problem is likely. However, there is only an indication of the problem and the exact problem cannot be confirmed objectively without further detailed information.

38. Again, using misalignment as an example, if misalignment exists it may not significantly affect serviceability but it may be an indication that a structural failure--such as a tie-rod failure, sheet bending failure, or passive soil failure at the toe--has occurred or is in progress. Thus, although the exact cause and effect of the misalignment cannot be pinpointed without further investigation, the condition index of the structure should reflect some increased safety risk. For this example and many others, the increased risk cannot be evaluated by a simple analytical means; thus, it cannot be included in the structural condition index. It is, therefore, appropriate to reduce the functional condition index. As one can conclude, a distress such as misalignment may be included in the structural condition index or the functional condition index depending upon the level of investigation, that is, objective versus subjective information. Since the analysis in this investigation is at an elementary level (see Appendix B), only one distress (scour) is included in the safety condition index.

39. Typically, each distress will be measured by some geometric or numerical quantity X, such as misalignment, settlement, or number of holes. Hence, in the case of misalignment, X will be the deviation of the wall from its design condition. Appendix C describes X in more detail. Such measurable

X must be reasonably repeatable. In Appendix C, the functional condition index is related to the ratio

$$\frac{X}{X_{max}}$$

where X_{max} is some limiting value of X. Referring to the above description of action zones (Table 2), X_{max} is selected as the point at which the subjective condition index is 40, that is, the dividing point between Zone 2 and 3. Following the discussion in the paragraphs above, X_{max} for misalignment has been selected by experts to be the point at which the misalignment requires immediate repair or, at a minimum, a more detailed inspection and condition index evaluation must be made. It is a potentially hazardous situation. The expert will have made the judgment for X_{max} based on serviceability and/or subjective safety considerations. Tables of X_{max} are given in Appendix D for several distresses.

Combined Condition Index

40. As the condition index zones in Table 2 indicate, one purpose of the condition index is to draw attention to a particular problem that may require further investigation (Zone 3). In this regard, the combined condition index or, simply, the condition index will be defined as

Condition Index = Minimum of:
Structural Condition Index
Functional Condition Index

Hence, if the structure has a poor condition index, a flag is raised and the engineer can trace back to determine whether the cause is a low structural or functional condition index. Indeed, the engineer would presumably trace back through the entire rating process and, possibly, conduct a more detailed field inspection and/or structural analysis to establish the basic cause.

Steel Sheet Pile Distresses

41. If a steel sheet pile structure is designed and constructed properly, it has an initial condition index of 100. As time passes and the structure is exposed to varying environmental and operational situations, its condition will deteriorate. The condition index will degrade as various distresses are incurred. A total of eight distresses has been identified for categorization in this project. Each is described briefly in Table 3 and in more detail in Appendix D. Each of these distresses can detract from the safety and serviceability of the steel sheet pile. For each of these cases, the magnitude of the distress is recorded during the inspection, as discussed in Part II. Consistent with the guidelines in the section called "Inspection Concepts," the field measurement is kept as simple as possible. The effect of the distress on the condition index depends upon the value of this measurement. The ratio of the field measurement to the limit X_{max} is used to calculate the serviceability condition index (see the section called "Functional Condition Index" and Appendix C). The limits for each distress are presented in Appendix D.

PART III: THE INSPECTION FORM AND EVALUATION MODEL

42. A concept behind the inspection form and the computer-based evaluation model is to keep the procedures and tools of implementation as simple as possible. While this might imply the end result is also "simple," this is not the case with the evaluation model. The "expert opinion" rules embedded in the computer-based evaluation model have been designed to interpret straightforward visual observation data in much the same manner as a seasoned engineer would interpret field observations. This section outlines the implementation procedures for the inspection form and the computer-based evaluation model.

Overview of the Inspection Form

43. The inspection form in Figure 5 has been designed to provide flexibility in documenting a variety of field conditions within one uniform form. Understanding the condition index requires thorough documentation of several characteristics of the steel sheet pile structure: (1) the history of the structure, (2) the structural components and related factors, and (3) the incidence of distresses that detract from the original condition of the steel sheet pile structure. Each of these characteristics is addressed by individual parts of the inspection form. Though there are seven pages in the inspection form, not all pages are used for every structure nor will every question have an answer. The following section illustrates the use of the inspection form. The following paragraphs briefly outline the inspection form.

Historical Information

44. Historical information related to the steel sheet pile structure being inspected is recorded on pages 1 and 2. Information requested includes project reference data to identify and to locate the specific structure. Further data categorize the structure into a particular type and function. This information assists the inspector to determine which of the structural component forms (page 3, 4, or 5) is to be completed. The information is also used to sort through the expert rules base in the evaluation model. The recent history of maintenance, modifications, inspections, and the like is recorded. Finally, a section to record present-day physical conditions of

nonessential steel sheet pile accessories is also provided in this part of the inspection form.

Structural Components

45. Information relative to the structural components of specific steel sheet pile structures is recorded on page 3, 4, or 5 of the inspection form: Page 3 is used for anchored (tied-back) or cantilevered wall types, page 4 for single cells, and page 5 for multiple-cell walls or bulkheads. The page is determined by the structure type and/or wall system type selected on page 1 of the inspection form. The information compiled on these pages provides the basis for an elementary review of the structural adequacy of the structure. This review is done automatically in the evaluation model as described in Appendix B. Most of the structural data will be recorded on the form prior to the site visit and verified during field inspection. The prior information may be taken from original design drawings, as-built construction drawings, or drawings of field modifications to the structure. The structural data forms are set up to record multiple subsections of wall types or cellular structures. Whenever there is a change in steel sheet pile components or construction conditions along a wall length, the subsection changes. It is not unusual in a steel sheet pile project for a wall section to be composed of two or three subsections of wall with variable sized components or different construction conditions. For example, the first 500 feet of wall might be a PZ27 steel sheet pile cross-section and the second 500 feet a PZ32. Or another example: the overall length of the steel sheet pile might become shorter over the length of the wall because the pile steps up with the rising grade of the river bottom. A separate structural data sheet is filled out for each subsection, that is, as many copies of page 3 as required. The use of station-to-station references for distance location of subsection changes further identifies the wall characteristics.

Loading and Dredge Line

46. Page 6 of the inspection form provides additional information required to review the structural adequacy of the steel sheet pile structure. The format of the sheet allows one section for specific information regarding load magnitudes (surcharges) and location by station reference along the structure length. The second section, for dredge depths,

records the existing grade levels of the dredge line or river bottom. This information is correlated with the structural component data from pages 3, 4, or 5 to give a safety condition evaluation along all points of the structure length.

Distress Profile

47. The distress profile form, page 7 of the inspection form, is a record of distresses in the SSP structure. The distresses are listed at the bottom of page 7 for easy reference. Refer to Paragraph 41 and Appendix D for more complete descriptions of the distresses and their limits.

General Notes

48. The layout of the inspection form in Figure 5 has been designed to facilitate both the data collection process and the computer input and evaluation model. After the initial inspection and computer modeling of a structure, the data on pages 1 through 5 will become relatively permanent and will require only nominal editing of computer data files to make them current again. Pages 6 and 7, however, are data pages that, in general, must be filled out in the field during the inspection because the information is subject to change. The following pages of this manual duplicate the actual inspection form with entries from an actual test inspection. The side-by-side arrangement of the following pages displays specific explanations adjacent to the entry on the inspection form. Pages 6 and 7 also have notes on how to measure and record critical data.

49. For all pages on the inspection form, station coordinates are used to locate structure characteristics or distresses. This reference is the familiar civil engineering standard of 0+00 equals a starting point and 1+50 is 150 feet away from the starting point. It is important that the station references on all pages of the inspection form be consistent. This should be discussed and agreed upon before the field inspection. The sketch on Attachment 5 of the inspection form is used to identify the beginning station reference location. Station locations should be entered as whole numbers, that is, 250 in lieu of 2+50.

U.S. ARMY CORPS OF ENGINEERS
STEEL SHEET PILE STRUCTURE INSPECTION

NAME OF CIVIL WORKS PROJECT:

(1): LAGRANGE LOCK & DAM

(2): UPPER GUIDEWALL

LOCATION OF CIVIL WORKS PROJECT:(1. Indicate body of water, and 2. nearest town)

(1): ILLINOIS WATERWAY

(2): BEARDSTOWN, IL.

DATE OF INSPECTION: 8-5-86 INSPECTED BY: L. GREIMANN, J. STECKER

PLEASE INDICATE THE TYPE OF STEEL PILE STRUCTURE INSPECTED
(NOTE: Use one inspection form per structure. Later data collected on this form is specific to only one structure type.)

1. Lock Chamber Wall
2. Lock Guide Wall
3. Transition or Retaining Wall
4. Guard Wall
5. Single Cell

STRUCTURE TYPE: (No.) 2

TYPE OF WALL SYSTEM: (Ignore if single cell structure)

1. Anchored (tie-back) or Cantilever
2. Cellular:

WALL SYSTEM: (No.) 1

LENGTH OF WALL OR CIRCUMFERENCE OF CELL STRUCTURE (ft): (NO.) 565

LOCATION OF STRUCTURE:
FACING DOWNSTREAM, WHICH SIDE IS THE STRUCTURE? (1.Right 2.Left): (No.) 2
IN RELATION TO THE LOCK, IS IT? (1. Upstream 2. Downstream): (No.) 1
PROXIMITY TO LOCK PROJECT SITE? (1. Near Lock 2. Remote): (No.) 1

LENGTH OF LOCK CHAMBER (ft): (NO.) 600

CONSTRUCTION DATE: 1939

ARE DRAWINGS AVAILABLE FOR REFERENCE?: (YES/NO) YES
ARE THE DRAWINGS INCLUDED WITH THIS FILE?: (YES/NO) NO

PRESENT WATER LEVEL: 429.0 (Reference to mean sea level elevation)
RECORD LOW WATER LEVEL: ?
RECORD HIGH WATER LEVEL: 447.25

Figure 5. Inspection form and comments (Sheet 1 of 24)

Page 1 Comments: Historical and/or Recordkeeping Data

Completed prior to the site inspection and verified and/or changed during the site inspection.

Data blanks on page 1 prefaced by (No.) ____ must be recorded as numbers.

Enter in (1) the CORPS OF ENGINEER PROJECT TITLE (55 characters). Line (2) is for additional title description.

Indicate the BODY OF WATER (1). This may be a river, canal or improved channel, lake, or coastline.

Indicate SSP STRUCTURE TYPE and WALL SYSTEM TYPE by entering the appropriate number in the blank following each name. Refer to the section called "Steel Sheet Pile Component Identification" for descriptions and illustrative figures if additional information is required to identify structure or wall types.

NOTE: Only one structure type is allowed on one inspection form. Page 3, 4, or 5 (of this inspection form) is selected for further data collection based on the selections made in these two questions.

Actual length of SSP STRUCTURE to nearest whole foot. For SINGLE CELL STRUCTURES, the circumference of the cell is recorded.

Enter nominal LENGTH OF LOCK CHAMBER (e.g., 600 ft or 1200 ft).

Information from the design or as-built drawings is necessary to complete structural data sections on page 3, 4, or 5 later in this form. The drawings may be useful for review in the field during an inspection.

Water level gauge readings referenced to mean sea level. PRESENT and RECORD LOW and HIGH WATER LEVELS are important for reference at a later date. Low and high water levels are used in some safety calculations. Include the date if known.

Figure 5. (Sheet 2 of 24)

GENERAL INFORMATION - Use the back of this page to list additional information that will not fit in spaces provided.

PAST 10 YEAR HISTORY OF:

MAJOR MAINTENANCE, REPAIRS, OR OTHER MODIFICATIONS

	DATE	DESCRIPTION
(1):	7	CURVED SECTION @ END EXTENSIVELY REPAIRED
(2):		AFTER IMPACT DAMAGE
(3):		

CHANGES IN BACKFILL, BUILDING STRUCTURES, ROADS, EQUIPMENT, STOCK PILES, ETC. ADJACENT TO STRUCTURE, OR BEHIND STRUCTURE UP TO A DISTANCE OF 1/2 THE SSP STRUCTURE HEIGHT

	DATE	DESCRIPTION
(1):		NONE
(2):		
(3):		

PREVIOUS INSPECTIONS OR STRUCTURAL REVIEWS (Attach copies if available)

	DATE	DESCRIPTION
(1):		UNKNOWN
(2):		
(3):		

PRESENT DAY: - Use this section of the Inspection Form to describe the location and physical condition of SSP accessories such as Cap, Railing, Armor Protection, Fender, Mooring Posts, Rings, etc.

	STATIONS FROM	TO	DESCRIPTION (Materials, type connections, etc.)
Ex.1	0	600	Fenders, 3 Rows 8 x 8 Oak Timbers
Ex.2	250	300	Steel Channel Cap is missing
(1):	0	565	TIMBER FENDERS, 3 ROWS 8x12 OAK
(2):	0	565	STEEL PLATE CAP
(3):	0	565	CABLE HANDRAIL
(4):	0	565	MOORING POSTS @ 50' INTERVALS
(5):			
(6):			
(7):			
(8):			
(9):			
(10):			

Attach a general site plan of the civil works project. Use ATTACHMENT FORM A or other available plan and include with the Inspection Form.

Attach a sketch of the particular SSP section covered by this inspection. Use ATTACHMENT FORM B or other plan and include with the Inspection Form.

Figure 5. (Sheet 3 of 24)

Page 2 Comments: Historical and/or General Data

Completed prior to the site inspection and verified and/or changed during the site inspection.

The first three sections are expanding records and can record up to five lines of data. Dates and descriptions are entered on one line as one record. Each record is limited to 70 characters.

Enter SSP component MODIFICATIONS or REPAIR operations performed on the structure within the last 10 years.

Examples: 1977 Sandblast and epoxy paint all exposed steel
1979 Replace SSP Sta. 100 to 120 from tow collisions in 1978

Enter CHANGES OF BACKFILL from original construction; record additions or removal of building structures, roads, heavy equipment, material stockpiles, and the like from the area immediately behind the SSP or within the area of SSP cells.

Example: 1981 Store concrete rubble Sta. 350 to 550 to load barges for transfer to dam site

Note: two records were used for one note.

Enter brief description of any PREVIOUS INSPECTIONS OR STRUCTURAL REVIEWS of the specific structure inspected. General inspections of the civilian work project should be cited when the structure is specifically noted.

Example: 1981 Structural review of anchor rating for surcharges.

Enter PRESENT DAY status of miscellaneous SSP accessories observed during the inspection of the structure. The items noted in this section are for information only and do not affect the condition index rating of the structure. They are recorded in the inspection file so that future observations can note changes that have occurred in the accessories. See Ex. 1 and 2 on form at left. This section can be expanded up to 20 records. Stations and description are entered on one line and are one record. As in the example above, it is acceptable to use two records to define one condition.

Sketch a general layout drawing on ATTACHMENT A or attach a copy of the project site plan. Note locations of SSP structures.

Sketch a general layout of the SSP structure or attach a detail design drawing laying out the structure as ATTACHMENT B. Note the beginning station reference must coincide with rest of inspection pages.

Figure 5. (Sheet 4 of 24)

ANCHORED OR CANTILEVER WALL CROSS-SECTION

NOTES FOR USE OF THIS DATA PAGE:

1. Use this Data Page for recording dimensions if the wall system selected on Page 1 is an anchored or cantilevered wall.
2. Use more than one sheet for recording data on multiple subsections of the wall components or measurements for the cross-section change.

FROM STATION: 0
TO STATION: 565

WALL TYPE:
1. Anchored
2. Cantilever
(No.) 1

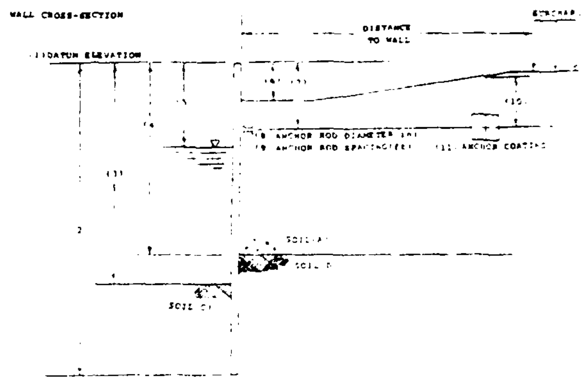
ANCHOR SYSTEM DRAWINGS ATTACHED?
(YES/NO) NO

SOIL COMPOSITION:

1. Sand	5. Medium Clay
2. Gravel	6. Stiff Clay
3. Rock	7. Unknown
4. Soft Clay	

SOIL(A): (No.) 2
SOIL(B): (No.) 5
SOIL(C): (No.) 5

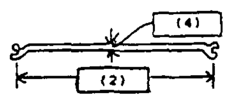
Figure 1.



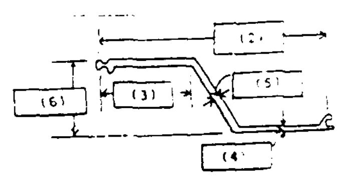
WALL CROSS-SECTION: (Refer to Figure 1)

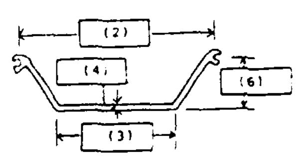
(1) DATUM ELEVATION: 434.0
(2) PILE LENTH(ft): 38
(3) TOP-TO-DREDGE(ft): 23
(4) TOP-TO-SOIL(B) (ft): 23
(5) TOP-TO-WATER(ft): 55
(6) TOP-TO-SOIL(A) (ft): 0
(7) TOP-TO-ANCHOR ROD(ft): 7-0
(8) ANCHOR ROD DIAMETER(in): 2.25
(9) ANCHOR ROD SPACING(ft): 8-0
(10) ANCHOR DEPTH(ft): 7-0
(11) ANCHOR ROD COATING: ?

Figure 2.



PILE CROSS-SECTION: Provide the Design SSP SECTION SHAPE DESIGNATION (Ex. PZ32 or PSA28) in (1.) or dimension the appropriate section as shown at the right in Fig. 2 in blanks (2) thru (6).





(1) SECTION DESIGNATION: MZ38
(2) DRIVING WIDTH(in): ______
(3) FLANGE WIDTH(in): ______
(4) FLANGE THICKNESS(in): ______
(5) WEB THICKNESS(in): ______
(6) CROSS-SECTION DEPTH(in): ______
(7) YIELD STRENTH: ______
(If left blank, 36,000 is assumed)

Figure 5. (Sheet 5 of 24)

Page 3 Comments: Structural Components Data

Complete data entry on page 3 if:

- Structure type noted on page 1 is Type 1, 2, 3, or 4 and
- Wall type noted on page 1 is No. 1 (anchored or cantilever).

Complete prior to the site inspection and verify and/or change data during the site inspection. Data blanks on page 3 prefaced by (No.) ____ must be recorded as numbers.

It is possible to have more than one configuration (or cross-section detail) of an SSP structure. When the configuration changes, use additional sheets of this form to record the separate subsections of the wall.

Examples: Use two forms for the following condition

Sta. 0 to 250	Design pile length is 28 ft
Sta. 250 to 600	Design pile length is 34 ft

NOTE: The beginning station reference for the first subsection must be the same as the beginning station on the other inspection form pages.

WALL TYPE: Select anchored or cantilever. If unsure of condition, review design drawings. This selection is used in the safety condition index analysis.

SOIL COMPOSITION: Select the appropriate soil type from information usually found on the as-built construction drawings. If Type 7 (unknown) is selected, the soil is assumed to be soft clay.

WALL CROSS-SECTION: Provide the information requested based on dimensions available on the design drawings. The dimensions must be entered in the order noted and in the units noted.

PILE CROSS-SECTION: Figure 2 on the opposite page illustrates the several SSP shapes that have been and are currently available. The section designation (1) must be entered into the computer program. If it is not available on the drawings, record the field dimensions for the actual SSP sheet, i.e., (2) through (6), and see Appendix A for several tables of SSP sheet sections. Select the section that matches most closely the dimensions (2) through (6) and enter this section designation in (1).

YIELD STRENGTH: Several yield strength steels are used in SSP sheets. If a yield strength is known, e.g., 55,000 psi, enter the value in this entry. The default is 36,000 psi.

Figure 5. (Sheet 6 of 24)

NOT APPLICABLE TO LAGRANGE UPPER GUIDE WALL

SINGLE CELL CROSS-SECTION

NOTES FOR USE OF THIS DATA PAGE:
1. Use this Data Page for recording dimensions if a single cell is the structure type selected on Page 1.
2. Only one cell can be recorded on this Data Page. Use a separate inspection form, Pages 1, 4, etc., to record each individual cell.

CELL CROSS-SECTION: (Refer to Figure 1 or 2)
(1) DATUM ELEVATION: (ft.) ________
(2) TOP-TO-WATER: (ft.) ________
(3) TOP-TO-DREDGE: (ft.) ________
(4) PILE LENGTH: (ft.) ________
(5) CELL DIAMETER: (ft.) ________

LOADING ON CELL: (Refer to Figure 1 or 2)
P = HORIZONTAL: (lbs) ________
(Concentrated pull or impact load)
Q2= SURCHARGE: (Uniform PSF) ________

INTERIOR BACKFILL AND FOUNDATION MATERIAL:
1. Sand 2. Gravel 3. Rock
4. Soft Clay 5. Medium Clay 6. Stiff Clay
7. Unknown

SOIL (A): (No.) ________ Interior backfill
SOIL (B): (NO.) ________ Foundation soil or rock
SOIL (C): (No.) ________ Soil layer over rock

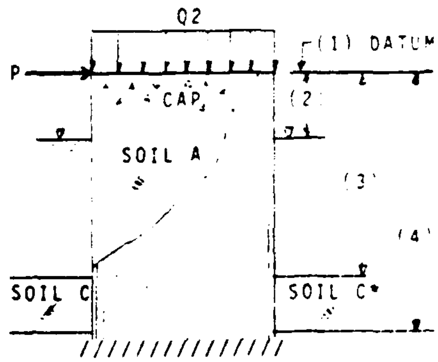
PILE CROSS-SECTION: (Refer to Figure 3)
Provide the Design SSP SECTION SHAPE DESIGNATION (1) (Ex. PSA28); or dimension the DRIVING WIDTH (2) & FLANGE THICKNESS (3).

(1) SECTION DESIGNATION: ________
(2) DRIVING WIDTH: (IN.) ________
(3) APPROX. THICKNESS: (IN.) ________

CELL CAP:
TYPE (None, Concrete, Asphalt, etc.): ________
THICKNESS OF CELL CAP: (ft.) ________
ACCESS MANHOLE/PORT EXIST?: (YES or NO) ________

CELL PURPOSE:
(1. Protection, or 2. Mooring): (No.) ________

FIGURE 1: ROCK OR STIFF CLAY FOUNDATION



NOTE: *SOIL C MAY BE ABSENT WITH ROCK OR COULD BE ANY OTHER SOIL TYPE

FIGURE 2: SAND, GRAVEL, OR SOFT TO MEDIUM CLAY

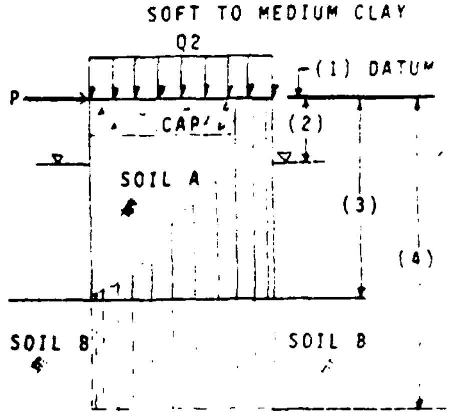
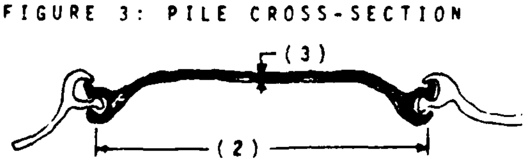
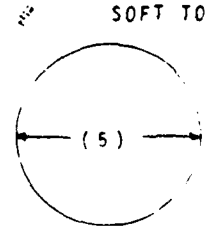


FIGURE 3: PILE CROSS-SECTION





PLAN - BOTH FIG.

Figure 5. (Sheet 7 of 24)

Page 4 Comments: Structural Components Data

Complete data entry on page 4 if structure type noted on page 1 is Type 5.

Complete prior to the site inspection and verify and/or change data during the site inspection.

Data blanks on page 4 prefaced by (No.)____ must be recorded as numbers.

It is not likely to have more than one configuration of steel sheet pile within one cellular SSP structure. However, if the configuration changes, use additional sheets of this form to record the separate subsections of the cell.

CELL CROSS-SECTION: Provide the information requested based on dimensions available on the design drawings. The dimensions must be entered in the order noted and in the units noted. These data are used in analysis of factors of safety for the SSP components. Occasionally the pile lengths will vary around the circumference of the cell. When that occurs, enter the shortest pile length (4).

LOADING ON CELL: The force P represents a concentrated force applied to the cell, for example, by a barge. It may include impact. Q2 is a uniform surcharge applied to the top at the cell.

INTERIOR BACKFILL MATERIAL: Select the appropriate soil type from information usually found on the as-built construction drawings. If Type 7 (unknown) is selected, the soil is assumed to be soft clay. Figure 1 opposite is used if the foundation is rock or soft clay; otherwise, Fig. 2 opposite is used.

PILE CROSS-SECTION: Figure 3 on the opposite page illustrates the typical SSP shape that has been used for cells and is currently available. The SSP section designation (1) must be entered into the computer program. If it is not available on the drawings, reccrd the field dimensions for the actual SSP sheet (2) and (3) and see Appendix A for several tables of SSP sheet sections. Select the section that most closely matches the dimensions (2) and (3) and then enter this section designation in (1) and the computer program.

CELL PURPOSE: The purpose of the single cell is significant in the evaluation of the service condition index for the cell structure. See Appendix D.

Figure 5. (Sheet 8 of 24)

MULTIPLE CELL CROSS SECTION PROFILE

NOT APPLICABLE TO LAGRANGE UPPER GUIDE WALL

NOTES FOR USE OF THIS DATA PAGE:

1. Use this Data Page for recording dimensions if the wall system selected on Page 1 is a cellular wall.
2. Use more than one sheet for recording data on multiple subsections of the wall components or measurements for the cross-section change.

FROM STATION: __________
TO STATION: __________

CROSS-SECTION TYPE: (Case No.) __________
Refer to Figure 1 on the back of this page to select the Case Type No. 1 to 4 appropriate to this subsection of wall.

CELL TYPE: (Refer to Fig. on back of 5)
(1.DIAPHRAGM, 2. CIRCULAR): (No.) __________

CELL CROSS-SECTION (Refer to Figure 1 for 1 - 6, and Figure 2 for 7 - 9)

(1) DATUM ELEVATION:		__________	
(2) TOP-TO-HIGH SIDE WATER(ft):	(ft.)	__________	(Cases 1 & 3 only)
(3) TOP-TO-SOIL(C) in Cases 1 & 2	(ft.)	__________	(Soil(B) in Cases 3 & 4)
(4) PILE LENGTH:	(ft.)	__________	
(5) TOP-TO-LOW SIDE WATER:	(ft.)	__________	
(6) TOP-TO-DREDGE:	(ft.)	__________	(Low water side)
(7) MAXIMUM CELL WIDTH:	(ft.)	__________	
(8) CELL SPACING:	(ft.)	__________	
(9) ARCS ANGLE:	(Deg)	__________	(Circular Cell type only)

LOADING ON CELLULAR WALL: (Refer to Fig. on back of 5)
Q2= SURCHARGE: (Uniform PSF) __________
Note: When a loading occurs on the soil behind the wall, e.g. as Q1 is shown in Cases 2 & 3, this loading must be entered in the Loading Table in Page 6 of the Inspection Form.

INTERIOR BACKFILL AND FOUNDATION MATERIAL: (Refer to Fig. on back of 5)
1. Sand 2. Gravel 3. Rock
4. Soft Clay 5. Medium Clay 6. Stiff Clay 7. Unknown

SOIL (A): (No.) ______ Interior backfill
SOIL (B): (NO.) ______ Foundation soil or rock
SOIL (C): (No.) ______ Soil layer over rock
SOIL (D): (No.) ______ Backfill behind wall

PILE CROSS-SECTION: (Refer to Fig. on back of 5)
Provide the Design SSP SECTION SHAPE DESIGNATION (1) (Ex. PSA28); or dimension the DRIVING WIDTH (2) & FLANGE THICKNESS (3).

(1) SECTION DESIGNATION: __________
(2) DRIVING WIDTH: (IN.) __________
(3) APPROX. THICKNESS: (IN.) __________

CELL CAP:
TYPE (None, Concrete, Asphalt, etc.): __________
THICKNESS OF CELL CAP: (ft.) __________
ACCESS MANHOLE/PORT EXIST?: (YES or NO) __________

Figure 5. (Sheet 9 of 24)

Page 5 Comments: Structural Components Data

Complete data entry of page 5 if:

- Structure type noted on page 1 is Type 1, 2, 3, or 4 and
- Wall type noted on page 1 is No. 2 (cellular).

Complete prior to the site inspection and verify and/or change data during the site inspection.

Data blanks on page 5 prefaced by (No.)____ must be recorded as numbers.

Multiple cell structures are similar to walls in that they have a linear configuration and function similar to a wall and thus can be identified readily with station references.

It is possible to have more than one configuration (or cross-section detail) of a SSP structure. When the configuration changes, use additional sheets of this form to record the separate subsections of the wall.

NOTE: The beginning station reference for the first subsection must be the same as the beginning station referenced on the other inspection form pages.

CROSS SECTION TYPE: See next page for description.

CELL TYPE: Select diaphragm or circular. If unsure, review design drawings. This selection is used in safety condition index analysis (see Fig. 2 on next page).

CELL CROSS-SECTION: Provide the information requested based on dimensions available on the design drawings. The dimensions must be entered in the order noted and in the units noted. These data are used in analysis of factors of safety for the SSP components.

LOADING ON CELLULAR WALL: Q2 is the surcharge on the top of the cell. Loadings behind the wall, e.g., Q1 in Case 2 and 3 are entered on page 6.

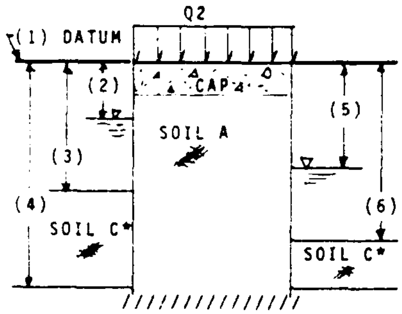
BACKFILL MATERIAL: Select the appropriate soil type from information usually found on the as-built construction drawings. If Type 7 (unknown) is selected, the soil is assumed to be soft clay.

PILE CROSS-SECTION: Figure 3 on the next page illustrates the typical SSP shape that has been used for cells and is currently available. The SSP section designation (1) must be entered into the computer program. Also, see page 4 of Inspection Forms.

Figure 5. (Sheet 10 of 24)

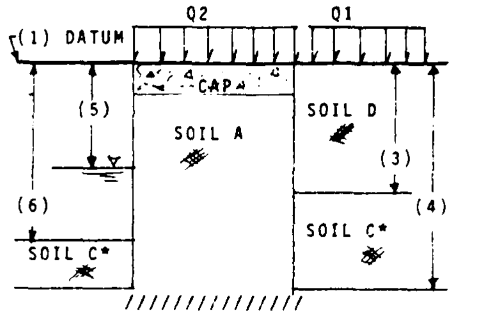
Fig. 1. Wall cross-section conditions by case types.

CASE 1: ROCK OR STIFF CLAY FOUNDATION WITH DIFFERENT WATER LEVELS ON EITHER SIDE OF CELLULAR WALL



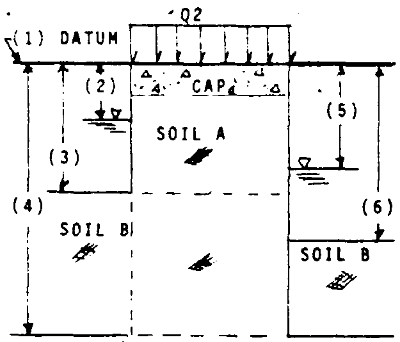
SOIL B = ROCK OR STIFF CLAY
*NOTE: SOIL C MAY BE ABSENT WITH ROCK OR COULD BE ANY OTHER SOIL TYPE

CASE 2: ROCK OR STIFF CLAY FOUNDATION WITH WATER ON ONE SIDE AND EARTH FILL ON THE BACK SIDE OF THE WALL



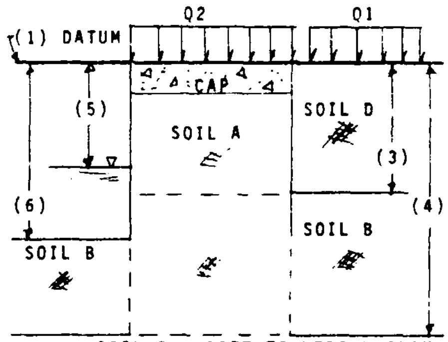
SOIL B = ROCK OR STIFF CLAY
*NOTE: SOIL C MAY BE ABSENT WITH ROCK OR COULD BE ANY OTHER SOIL TYPE

CASE 3: SAND, GRAVEL, OR SOFT TO MEDIUM CLAY FOUNDATION WITH DIFFERENT WATER LEVELS ON EITHER SIDE OF THE CELLULAR WALL



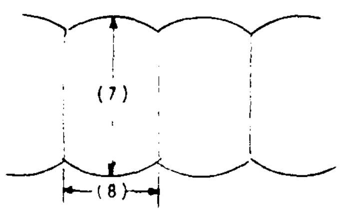
SOIL B = SOFT TO MEDIUM CLAY

CASE 4: SAND, GRAVEL, OR SOFT TO MEDIUM CLAY FOUNDATION WITH WATER ON ONE SIDE AND EARTH FILL ON THE BACK SIDE OF THE WALL

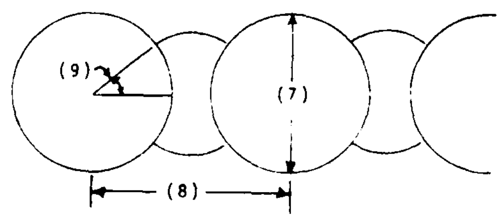


SOIL B = SOFT TO MEDIUM CLAY

Fig. 2. Cell types.



DIAPHRAGM TYPE WITH STRAIGHT OR CURVED CROSS WALLS



CIRCULAR TYPE

Fig. 3. Pile cross-section.

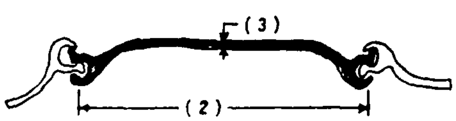


Figure 5. (Sheet 11 of 24)

CROSS SECTION TYPE: Figure 1 opposite is used to identify various cross-section cases that are utilized in the structural analysis. Different assumptions and calculations are associated with each case (see Appendix B). Generally, the cases differ by foundation type and loading condition on the back (right) side of the wall:

Case	Foundation	Right Side
1	Rock or Stiff Clay	Water
2	Rock or Stiff Clay	Soil
3	Other	Water
4	Other	Soil

Figure 5. (Sheet 12 of 24)

LOADING AND DREDGE DEPTH PROFILE DATA SHEET

GENERAL INFORMATION - Use the back of this page or another data sheet to list additional information that will not fit in spaces provided.

LOADING TABLE: Use this section to describe the location, loading weight per SF and a brief description of the type of loads applied to the SSP structure.

	STATIONS FROM	STATIONS TO	LOADING (psf)	DISTANCE TO WALL (ft)	DESCRIPTION OF LOADING
Ex.	135	215	300	12	Rock Stockpile
(1):	0	350	0		
(2):	350	450	300	6	STORAGE AREA ON CONC. PEDESTAL SLAB
(3):					
(4):					
(5):					
(6):					
(7):					
(8):					
(9):					
(10):					

DREDGE DEPTH ALONG STRUCTURE:

Measurement (or soundings) for Dredge Depth should be recorded at 50' intervals for walls along the entire length of the wall or at quarter points of the circumference of single cells. Specific station notation of greater depth holes, such as Ex. 2 should be noted at other than 50' intervals.

	STATION	DEPTH
Ex.1	50	23
Ex.2	87	25.8
(1):	100	23
(2):	150	23
(3):	200	24
(4):	230	25
(5):	250	28
(6):	300	28.5
(7):	350	29.5
(8):	400	30
(9):	450	29.5
(10):	500	30
(11):	550	28.5
(12):	565	28
(13):		
(14):		
(15):		
(16):		
(17):		
(18):		
(19):		
(20):		

Figure 5. (Sheet 13 of 24)

Page 6 Comments: Loading and Dredge Line Data

The LOADING TABLE: an expanding record field for up to 20 different combinations of locations and surcharge loads. These data do not need to be entered in order of stations; the computer will sort the records after all data are entered.

The factor of safety calculations outlined in Appendix B correlate SSP load capacities with the location of the loads and the recorded dredge depths from below. The station references must be in agreement with the subsection references on page 3, 4, or 5, because the structural data are selected from the appropriate section of wall.

The LOADING value, or surcharge, is expressed in pounds per square foot (psf). It is an estimate of the actual uniform surcharge applied to the soil behind the SSP structure. Surcharges of less than 150 psf can be ignored and not recorded. (A one-ft thick section of concrete, or a three-ft pile of wood materials weighs approximately 150 psf.) The DISTANCE TO WALL column lists the distance from the wall to the point at which the loading begins. The safety calculation assumes that any load is applied directly behind the wall and is a uniform intensity back from the wall. Applying the surcharges in this manner is conservative. The engineer can review and adjust the loading rates according to best judgment. The DESCRIPTION OF LOADING should provide additional information to the engineer to evaluate accurately the loads on the SSP structure. The description record is limited to 44 characters.

The DREDGE DEPTH PROFILE is a data file of up to 60 records of the DEPTH of the dredge line or river bottom relative to the top of the SSP structure. This dimension is the actual measurement of the exposed height, given as TOP TO DREDGE on the previous structural data pages. This measurement is directly correlated with the loading information above in computing the safety condition index. When this measurement varies from the design, it is said to have "scoured".

Measurement of the dredge line depth can be accomplished in a number of ways. The authors have used a weighted line to get reasonably accurate depth records. Sounding records in navigable waters may be available and provide reliable data, but these should be verified at several points. The authors believe several of the commercially available depth finders could also be used effectively. The authors recommend depth measurements be taken at 50 ft intervals except where sharply rising or falling grades suggest more frequent measurements. The depth should be measured adjacent to the wall and at some distance, say 5 ft, out from the wall to account for sloping fills, short berm areas, and/or walls adjacent to navigation channel lines. The lowest dredge valve should be entered. It should be noted that at least one depth record must be recorded to provide data for the safety analysis. The computer will sort the records according to station order after all data are entered.

Figure 5. (Sheet 14 of 24)

U.S. ARMY CORPS OF ENGINEERS
STEEL SHEET PILE STRUCTURE INSPECTION

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:

1. Use this DATA PAGE for recording pertinent information relative to the DISTRESS TYPES indicated below. Enter each occurence of a specific distress by recording the DISTRESS TYPE data in the appropriate section below. The appropriate units of measurement are noted in the column boxes.
2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	FROM TOP OF WALL
FT	FT	FT	IN	FT
150	200	190	6 1/2"	0
200	250	230	2 1/2"	0

CORROSION

STATION FROM	STATION TO	SEVERITY LEVEL (1-5)
FT	FT	#
0	565	2

SETTLEMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	SURFACE DESCR. TYPE *
FT	FT	FT	IN	#
160	200	190	10"	2
300	350	340	8"	2
390	400	398	14"	2
480	505	500	6"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION	LENGTH	FROM TOP OF WALL
FT	FT	FT

CAVITY FORMATION

CAVITY AT STATION	ESTIMATE CAVITY SIZE LENGTH	WIDTH	HEIGHT	SURFACE TYPE *
FT	FT	FT	FT	#

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION	HOLE SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	FT	FT

DENTS

DENT AT STATION	DENT SIZE LENGTH	WIDTH	DEPTH	FROM TOP OF WALL
FT	FT	FT	IN	FT
250	3'-0	2'-0	0-6"	0

CRACKS

CRACK AT STATION	CRACK SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	IN	FT
125	2-0	0	0
180	2-0	0	0
220	2-0	0	0

Figure 5. (Sheet 15 of 24)

Page 7 Comments: Distress Profile

Refer to Appendix D for more descriptive information about any distress type.

The equipment required to measure the distress characteristics are small hand tools. It is also necessary to have access to a boat. In the course of a typical inspection, the inspector will walk the top of the structure and get in the boat to observe all visible portions of the SSP structure.

The need for detailed accuracy in recording distress characteristics is limited. It is acceptable to record station references and location of maximum displacements to the nearest whole foot. The other dimensions requested as FT will generally be acceptable if recorded to the nearest whole inch increment, for example, 2 ft, 6 in. Those dimensions requested as IN. will generally be acceptable if recorded to the 1/2 in. increment.

The DISTRESS PROFILE FORM on the left is filled out with distress data observed at an actual test inspection and matches data on the previous pages of the inspection form.

On the following pages, additional copies of page 7A are used to further illustrate an example entry for each of the distresses. The form will also be used to note other pertinent comments for each distress. The entries on the following pages are not associated with any particular wall.

Figure 5. (Sheet 16 of 24)

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:

1. Use this DATA PAGE for recording pertinent information relative to the DISTRESS TYPES indicated below. Enter each occurence of a specific distress by recording the DISTRESS TYPE data in the appropriate section below. The appropriate units of measurement are noted in the column boxes.
2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	FROM TOP OF WALL
FT	FT	FT	IN	FT
125	165	145	10"	0
FOR A	CELL			
35	40	38	2"	2'-0

CORROSION

STATION FROM	STATION TO	SEVERITY LEVEL (1-5)
FT	FT	#
0	600	2

SETTLEMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	SURFACE DESCR. TYPE *
FT	FT	FT	IN	#
400	422	415	7"	2
FOR A	CELL			
0	105	80	5½"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION	LENGTH	FROM TOP OF WALL
FT	FT	FT
510	3'-0	3'-0

CAVITY FORMATION

CAVITY AT STATION	ESTIMATE CAVITY SIZE LENGTH	WIDTH	HEIGHT	SURFACE TYPE *
FT	FT	FT	FT	#
510	2'-0	2'-6	1-4	2

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION	HOLE SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	FT	FT
190	0-9"	1'-4"	4'-6

DENTS

DENT AT STATION	DENT SIZE LENGTH	WIDTH	DEPTH	FROM TOP OF WALL
FT	FT	FT	IN	FT
194	2'-0	2'-0	8"	4'-0

CRACKS

CRACK AT STATION	CRACK SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	IN	FT
240	2'-3	0	0-8"

Figure 5. (Sheet 17 of 24)

Distress Type 1--Misalignment

Line 1: Misalignment of a Wall
The measurement of misalignment can be made with a tape measure, a line, a two-ft level, and a straghtedge. The typical misalignment of a wall is represented by a bow or curvature in the wall that deviates from its initial alignment for some length. Refer to Appendix D (Figure D1) for types of misalignment and also illustrations of causes for failure. This line illustrates a bow in the wall that is 40 ft long. The bow is from Station 125 to 165 with a horizontal displacement of 10 in. from the design alignment of the wall. The point of maximum misalignment is Sta. 145 at the top of the wall.

Minimum Misalignment of a Wall:
In most walls, a misalignment of 2 or 3 in. or less can be ignored. However, if another distress such as settlement, a cavity, or a missing fixing bolt occurs at the same station location, then the misalignment should be recorded for monitoring its change over time.

Line 3: Misalignment of a Cell
The typical misalignment for a cellular structure, particularly a single cell, is out-of-plumbness. Cell misalignment is recorded by measuring the offset from the plumb line at the point of maximum offset. The location of this measurement must correspond with other location criteria relating to the cell configuration. For this example, the station location of the misalignment, or out-of-plumbness, is from Station 35 to 40 approximately one-third of the way around a 35-ft diameter cell. The beginning station location is referenced on the plan view of the cell structure attached to Page 2. The reading of the misalignment was 2.0 ft down from the top of the cell, and a 2-in. offset (from vertical line) was measured in the length of the 24-in. hand level. Cells will bulge and deform from an exact circle as they are filled. This naturally occurring bulge should not be interpreted as misalignment. An average of four measurements at 90-degree intervals will average out this initial bulging.

Minimum Misalignment of a Cell:
Construction standards allow up to 1/8 in. per foot variance from plumb or 1/4 in. per two foot. A minimum standard to record vertical misalignment could be 1/2 in. vertical offset per two foot.

Distress Type 2--Corrosion

Line 1: Corrosion
The rating of the deterioration of the steel sheet pile (SSP) structure due to corrosion is made in a subjective manner. Refer to Appendix D for a more detailed description of the rating system. Selection of the corrosion level observed on a particular section of a structure is made by comparing the observed condition to standards in Table D2 and/or visually comparing it to the photographs in Figure D3. In the field inspection the only comparison that can be made is a visual inspection of the exposed areas of the structures. There are six levels of deterioration within which to rate the structure. The default condition, Group 0, is new or nearly equal to new. This condition requires no entry on the Profile Form. For the remaining five levels, Groups 1 through 5, a selection must be made and assigned to specific locations of the structure. In this example, the entire length of a 600-ft wall, Sta 0 to Sta. 600, was rated at Level 2. An alternative example would be Sta. 0 to 300 rated at Level 2 and Sta. 300 to 600 rated Level 4, if there had been a major difference in deteriorated condition between the two sections of wall.

Figure 5. (Sheet 18 of 24)

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:

1. Use this DATA PAGE for recording pertinent information relative to the DISTRESS TYPES indicated below. Enter each occurence of a specific distress by recording the DISTRESS TYPE data in the appropriate section below. The appropriate units of measurement are noted in the column boxes.
2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	FROM TOP OF WALL
FT	FT	FT	IN	FT
125	165	145	10"	0
FOR A	CELL			
35	40	38	2"	2'-0

CORROSION

STATION FROM	STATION TO	SEVERITY LEVEL (1-5)
FT	FT	#
0	600	2

SETTLEMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	SURFACE DESCR. TYPE *
FT	FT	FT	IN	#
400	422	415	7"	2
FOR A	CELL			
0	105	80	5½"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION	LENGTH	FROM TOP OF WALL
FT	FT	FT
510	3'-0	3'-0

CAVITY FORMATION

CAVITY AT STATION	ESTIMATE CAVITY SIZE LENGTH	WIDTH	HEIGHT	SURFACE TYPE *
FT	FT	FT	FT	#
510	2'-0	2'-6	1-4	2

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION	HOLE SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	FT	FT
190	0-9"	1'-9"	9'-6

DENTS

DENT AT STATION	DENT SIZE LENGTH	WIDTH	DEPTH	FROM TOP OF WALL
FT	FT	FT	IN	FT
199	2'-0	2'-0	8"	4'-0

CRACKS

CRACK AT STATION	CRACK SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	IN	FT
240	2'-3	0	0-8"

Figure 5. (Sheet 19 of 24)

Distress Type 3--Settlement

Line 1: Settlement Behind an Anchored or Cellular Wall
The measurement of settlement can be made with a tape measure, a line, a two-ft level, and a straightedge. Measurement of settlement will be made at every location where a depression of soil occurs and where it appears to be inconsistent with the surrounding soil grade conditions. The settlement condition noted in this line suggests a depression approximately 22 ft long and 4 ft wide occurring from Sta. 400 to 422. The maximum depth of the settlement is 7 in. at Sta. 415. For settlement, it is also important to note what surface condition is met at the location of the settlement. For a wall, the program needs to know whether the backfill 1) is supporting a structure, 2) is surfaced with paving or sidewalk, or 3) has nothing on the surface. In this example, the number 2 recorded in the last column suggests a pavement or sidewalk was present at the time of the inspection.

In a cellular wall, settlment may occur under a cell cap structure without any visible shifting of the cap. This would reflect a surfacing condition type 2) with settlment under the paving. The only way this condition can be observed is by checking through an access port or manhole in the cap structure. When the condition exists, it approximates a large cavity until the cap settles down on the fill or the fill is replaced. When this type of settlment occurs and is observed, it should be recorded and the void height should be measured as the settlement of the fill.

Minimum Settlement at a Wall:
If the settlement occurs at or near the lock chamber, the minimum settlement that should be recorded is a 2 in. depression in less than 10 feet. If the settlement occurs away from a lock site, the minimum settlement that should be recorded is a 4 in. depression in less than 10 feet.

Line 3: Settlement of a Single Cell Interior Fill
Settlement of interior backfill material can occur and be observed as uniform settlement or as differential settlement. Uniform settlement of the top surface is measured from the original construction level or design level to the current level of the backfill material or cap at its highest point. Differential settlement of the top surface is characterized by a tilted cap structure or uneven slopes that have one point significantly lower than any other point or surface level. Differential settlement is measured from the level of the original construction surface or design level to the current level of the lowest point. The settlement condition noted in this line suggests that on a cell with a circumference of 105 ft, a differential settlement measuring 5 1/2 inches is located near Sta. 80 (going around the cell). For a cell, the type of settlement is recorded in the last column, "Surface Description Type," as either 1) for uniform settlement, or 2) for differential settlement.

Settlement may also occur under a single cell cap structure without any visible shifting of the cap. The only way this condition can be observed is by checking through an access port or manhole in the cap structure. When the condition exists, it approximates a large cavity until the cap settles down on the fill or the fill is replaced. When this type of settlment occurs and is observed, it should be recorded and the void height should be measured as the measured displacement of the fill.

Minimum Settlement of Cell Interior Fill:
If the settlement is uniform, the minimum settlement that should be recorded is a change of 2 in. or more. If the settlement is differential, any apparent settlement that can be measured should be recorded. This provides a record for future observation.

Figure 5. (Sheet 20 of 24)

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:
1. Use this DATA PAGE for recording pertinent information relative to the DISTRESS TYPES indicated below. Enter each occurence of a specific distress by recording the DISTRESS TYPE data in the appropriate section below. The appropriate units of measurement are noted in the column boxes.
2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	FROM TOP OF WALL
FT	FT	FT	IN	FT
125	165	145	10"	0
FOR A	CELL			
35	40	38	2"	2'-0

CORROSION

STATION FROM	STATION TO	SEVERITY LEVEL (1-5)
FT	FT	#
0	600	2

SETTLEMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	SURFACE DESCR. TYPE *
FT	FT	FT	IN	#
400	422	415	7"	2
FOR A	CELL			
0	105	80	5½"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION	LENGTH	FROM TOP OF WALL
FT	FT	FT
510	3'-0	3'-0

CAVITY FORMATION

CAVITY AT STATION	ESTIMATE CAVITY SIZE LENGTH	WIDTH	HEIGHT	SURFACE TYPE *
FT	FT	FT	FT	#
510	2'-0	2'-6	1-4	2

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION	HOLE SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	FT	FT
190	0-9"	1'-9"	9'-6

DENTS

DENT AT STATION	DENT SIZE LENGTH	WIDTH	DEPTH	FROM TOP OF WALL
FT	FT	FT	IN	FT
199	2'-0	2'-0	8"	4'-0

CRACKS

CRACK AT STATION	CRACK SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	IN	FT
290	2'-3	0	0-8"

Figure 5. (Sheet 21 of 24)

Distress Type 4--Cavity Formation

Line 1: Cavity Formation
The measurement of a cavity that is present behind an SSP wall or within an SSP cell is, at times, a difficult or impossible task. The access point to the cavity may prevent an accurate measurement of the length, depth, and height of the cavity. The equipment required to measure the cavity includes a flashlight, tape measure, and a length of wire that can be bent at angles to explore the concealed sections of the cavity. This line of data describes a cavity, behind a wall, that is 2 ft wide, 2 ft 6 in. high, and 1 ft 4 in. deep. The cavity occurs at Sta. 510 which coincides with the interlock separation recorded at Sta. 510. This illustrates the relationship that a cavity will normally have with a hole, crack, or separated interlock. For cavity formation, it is also important to note what the surface condition is above the cavity. For a wall or cellular structure, the program needs to know whether the backfill 1) is supporting a structure, 2) is surfaced with paving or sidewalk, or 3) has nothing on the surface. In this example, the number 2 recorded in the last column suggests a pavement or sidewalk was present at the time of the inspection.

Minimum Cavity Formation:
Any cavity formation with a depth exceeding 1 ft should be recorded. The inspector may record cavities of a smaller size if other conditions suggest they are increasing in size or could contribute to other problems.

Distress Type 5 --Interlock Separations

Line 1: The measurement of interlock separation is made with a tape measure. The incidence of interlock separation may occur in several different forms but the measurement will always be the same, that is, the length of the interlock connection that is no longer connected. The location of the interlock separation relative to the vertical dimensions of the structure is important, particularly in cellular-type structures. This line illustrates an interlock separation that occurs at Sta. 510 beginning 3 ft down from the top of the wall. The separation is 3 ft long. Every effort should be made to document accurately the total length of the interlock separation, particularly if the separation extends below the water level. This can be done by feel, by interviewing local staff, or by requesting information from local staff when the water level recedes.

Minimum Interlock Separation:
On a wall-type SSP structure, any separation that exceeds 12 in. in length should be recorded. On a cellular-type structure, all separations should be recorded.

Distress Type 6--Holes

Line 1: The measurement of holes is made with a tape measure. The relative height and width of the opening in the SSP section is recorded. The shape of

Figure 5. (Sheet 22 of 24)

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:

1. Use this DATA PAGE for recording pertinent information relative to the DISTRESS TYPES indicated below. Enter each occurence of a specific distress by recording the DISTRESS TYPE data in the appropriate section below. The appropriate units of measurement are noted in the column boxes.
2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	FROM TOP OF WALL
FT	FT	FT	IN	FT
125	165	145	10"	0
FOR A	CELL			
35	40	38	2"	2'-0

CORROSION

STATION FROM	STATION TO	SEVERITY LEVEL (1-5)
FT	FT	#
0	600	2

SETTLEMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	SURFACE DESCR. TYPE *
FT	FT	FT	IN	#
400	422	415	7"	2
FOR A	CELL			
0	105	80	5½"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION	LENGTH	FROM TOP OF WALL
FT	FT	FT
510	3'-0	3'-0

CAVITY FORMATION

CAVITY AT STATION	ESTIMATE CAVITY SIZE LENGTH	WIDTH	HEIGHT	SURFACE TYPE *
FT	FT	FT	FT	#
510	2'-0	2'-6	1-4	2

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION	HOLE SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	FT	FT
190	0-9"	1'-9"	9'-6

DENTS

DENT AT STATION	DENT SIZE LENGTH	WIDTH	DEPTH	FROM TOP OF WALL
FT	FT	FT	IN	FT
199	2'-0	2'-0	8"	4'-0

CRACKS

CRACK AT STATION	CRACK SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	IN	FT
240	2'-3	0	0-8"

Figure 5. (Sheet 23 of 24)

the opening, circular or oblong, is not as crucial as is the occurrence of an opening that does not have an intended or obvious use. This line illustrates an oblong opening (hole) that occurs at Sta. 190 that begins 4 ft, 6 in. down from the top of the wall. Additional information recorded an opening that is 9 in. long (measured horizontally) by 16 in. high or wide. The length of the opening is recorded as the horizontal dimension to indicate if more than one section is affected by the opening.

Minimum Size of Holes:
Any opening in an SSP section where the sum of the two recorded dimensions, length and height, will exceed approximately 8 in. should be recorded. For example, a round hole of 4 in. in diameter or an oblong hole 6 in. long by 2 in. wide should be about the minimum size opening recorded. An exception to this might be a smaller opening that is the apparent cause of another distress, such as settlement or cavity. The other distress should also be recorded for thorough documentation.

Distress Type 7--Dents
Line 1: Dents are measured with a tape measure. The relative height and width of the deformation is recorded. The shape of the deformation could be important if it is very large and affects several sections. However, in general, the dimensions of the length and height will be adequate. This line illustrates an approximately square deformation that occurs at Sta. 194. and begins 4 ft down from the top of the wall. Additional information describes a deformation that is 2 ft long by 2 ft high or wide and is displaced from the normal plane of the SSP section approximately 8 in. at its maximum displacement. The length of the deformation indicates if more than one section is affected by the deformation.

Minimum Size of Dent:
Any dent in an SSP section where the sum of the two recorded dimensions, length and width, will exceed approximately 18 in. should be recorded. For example, an oblong dent 8 in. by 10 in. or a creased dent 3 in. by 24 in. should be recorded.

Distress Type 8--Cracks
Line 1: The measurement of cracks in an SSP section is made with a tape measure. The incidence of a crack and its ramifications are very much like the discussion for interlock separation. Refer to that section, Distress Type 5--Interlock Separations, for specifics about measurement and concerns. This line illustrates a crack occurring at Sta. 240 that begins 8 in. down from the top of the wall and which is 2 ft, 3 in. long. The dimensions describe a horizontal crack traversing across the sheet.

Minimum Length of Crack:
A crack is not intended to be present, so any crack that exceeds 6 in. in length should be recorded.

Figure 5. (Sheet 24 of 24)

Computer-based Model

50. Computer programs associated with the inspection procedures and recordkeeping were developed on a personal computer. At some later date, various modules of the completed system will be integrated into a much larger maintenance management system currently under development by the U S Army Corps of Engineers. However, during the initial testing period, the Maintenance Management program herein described was set up to operate as a stand-alone system. This system includes modules for forms generation, data input procedures, evaluation of condition indexes, and report writing.

51. The program is designed to operate on an IBM-compatible personal computer with at least 512K of installed memory and two 360K, floppy disk drives. A hard disk is optional. The operating system is MS-DOS, Version 3.0. The program is written in MS-FORTRAN 77 language and is contained on two 360K floppy disks.

52. Disk 1 is a self-booting systems disk that also contains the control program and the main execution program. All command procedures required for program and file handling features are on Disk 1. Disk 2 contains the safety condition index evaluation. The user is instructed on the interaction of the two disks as well as the use of a data disk to create and store file records of the structure's inspection and the condition index data.

53. The structure of the project files is organized under the DOS directory and subdirectory system. The civilian work projects are the highest level and many steel sheet pile structures can be grouped under this project directory at a second level. Under each structure, data files pertaining to that structure and specific inspection data are in a third level of files. This file handling system allows the grouping of separate inspections on different structures under the same work project.

54. Once the program is started and the project file structure is set up, the program is menu-driven. In other words, all operations including file management, operation selection, and report writing are controlled from a main menu (e.g., see Table 4). Other menus further direct options.

55. After the program has been installed, the user begins by typing in the responses entered on the inspection sheet. The computer monitor is set up to look like the inspection sheet so that entry follows line by line.

Several editing features are available for correcting or updating. Pages 1 through 7 can be printed out as part of a report. They are not reproduced here because they would duplicate the ones presented previously. Once all data have been entered, the user may request the program to calculate the functional and the structural condition indexes by appropriate menu selections (Table 4). A SUMMARY REPORT, Page 8, that gives the condition indexes and summarizes the problems associated with this structure can also be printed. An example for the inspection forms earlier in this section is in Figure 6.

SUMMARY REPORT

PROJECT NAME:
LaGrange Lock & Dam
Upper Guide Wall

LOCATION:
Illinois Waterway
Beardstown, IL.

INSPECTION DATE: Aug. 5,1986

INSPECTED BY: L. Greimann, J. Stecker

STRUCTURE TYPE: Lock Guide Wall

STRUCTURE LOCATION: Left side, Upstream

The overall subjective condition and safety condition have been analyzed and compiled into the following indices:

FUNCTIONAL CONDITION INDEX = 35
STRUCTURAL CONDITION INDEX = 87

COMBINED CONDITION INDEX = 35

Additional intermediate data and evaluations that were incorporated into the calculation of the Functional Condition Index follow:

NUMBER OF DISTRESSES PRESENT AND THEIR CALCULATED DISTRESS COEFFICIENTS

2	Misalignment	35
1	Corrosion	69
4	Settlement	0
1	Dents	96
3	Cracks in Sheet	90

FUNCTIONAL CONDITION INDEX = 35

Additional intermediate data and assumptions that were incorporated into the calculation of the Structural Condition Index follow:

Station	Soil	Pile	Rod	SCI
400.00	1.28	7.96	3.77	87

Figure 6. Summary report (Continued)

Problems on this structure:

The following problems have been noted by this inspection and should be investigated further for maintenance or repair alternatives.

Missalignment functional condition index of 47 at station 4.
This missalignment condition is at or near the maximum allowable deviation and repair should begin soon.

Missalignment functional condition index of 75 at station 6.
This missalignment condition is becoming significant and maintenance to this level may be necessary.

Corrosion functional condition index of 69 at station 7.
This corrosion condition is deteriorated and requires extensive repair procedures to be controlled.

Settlement functional condition index of 21 at station 8.
This settlement condition exceeds the maximum allowable deviation. Other conditions may need to be corrected.

Settlement functional condition index of 29 at station 9.
This settlement condition exceeds the maximum allowable deviation. Other conditions may need to be corrected.

Settlement functional condition index of 11 at station 10.
This settlement condition exceeds the maximum allowable deviation. Other conditions may need to be corrected.

Settlement functional condition index of 40 at station 11.
This settlement condition requires maintenance.

Figure 6. (Concluded)

PART IV. FIELD TESTING

56. The inspection and rating procedure described in this report has been applied in two field tests. In July 1986 the procedure was applied to the upper and lower guide wall at Peoria Lock and Dam in Peoria, Ill. Four U S Army Corps of Engineer experts were involved in this testing: John Sirak (Ohio River Division), Richard Atkinson (Rock Island District), and Raymond Horton (Rock Island District). Dr. Anthony Kao, CERL project monitor, was also an observer. The results of that field test, although primarily qualitative in nature, were used to make several modifications to a previous version of the rating procedure. The results of that test are not specifically addressed here.

57. In July 1987 another field test was conducted in the Chicago area by four Corps engineers: Sirak, Atkinson, Horton, and Joseph Jacobazzi (North Central Division). Kao was also present. Several quite different SSP wall facilities were examined. Each expert was asked to rate the individual distresses in each wall and the overall wall, that is, assign a functional condition index. The results of this test are described below. As stated previously, many of the comments and suggestions made during that test have been incorporated into the current version of the procedure, that is, the version described herein. Additional details appear in Appendix E.

Descriptions

58. Nine different wall locations and functions were inspected during the Chicago field test.

Wall A (Figure 7)

59. Wall A is an anchored-type wall approximately 400 ft long that is used as a loading dock retaining wall. The wall height exposed above water was 7 ft and the overall height from top of wall to dredge averaged 24 ft. Anchor rods appeared to be 2.25 in. in diameter at 6 ft spacings. The steel sheet pile appeared to be PZ27. The observed distresses included two instances of misalignment with displacements of 8 in. over 75 ft and 5 in. over 20 ft, seven instances of dents with six being small (1 to 2 ft across) and one being much larger (9 ft by 3 ft and depressed 8 in.); and a general state

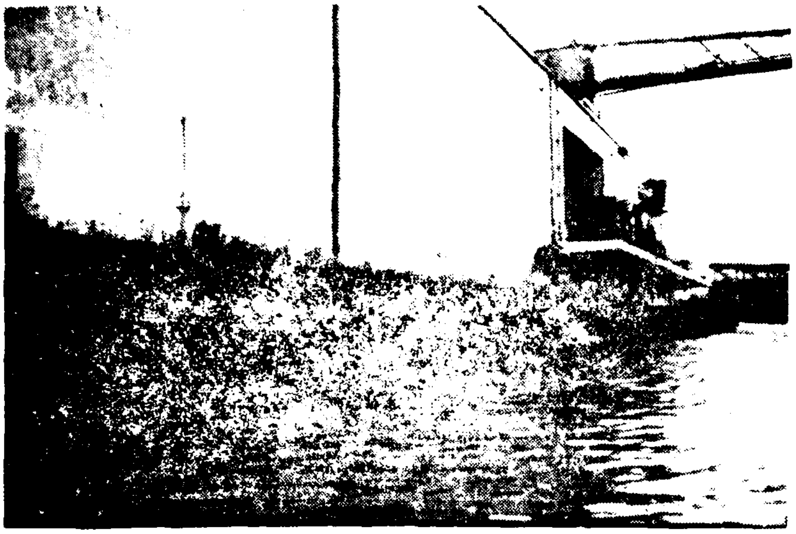


Figure 7. Wall A and B

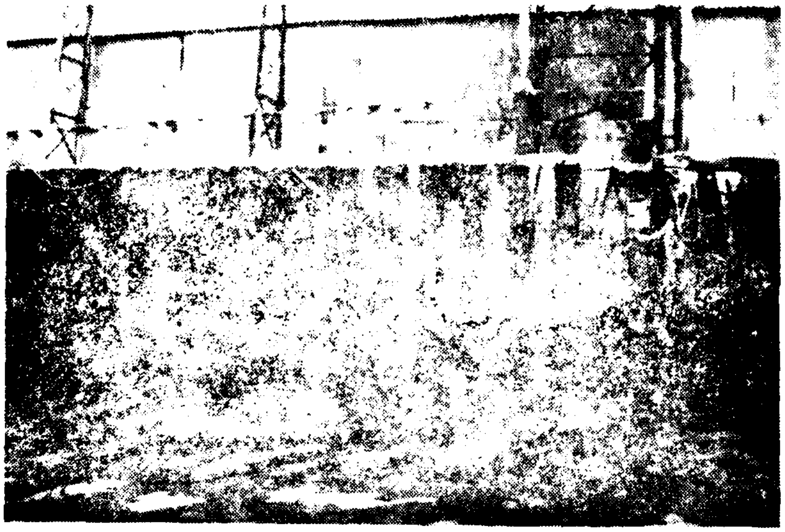


Figure 8. Wall C

of corrosion judged to be about Level 2. No other distresses were noted for the computer evaluation although several of the experts noted that they considered settlement behind the misalignment and also interlock damage and cracks in conjunction with the dents.

Wall B (Figure 7)

60. Wall B was, in fact, the same wall as Wall A. However, the experts were asked to rate the wall as if it were a guide wall in a lock and dam facility.

Wall C (Figure 8)

61. Wall C is an anchored-type wall approximately 285 ft long that is used as a loading dock retaining wall where salt is unloaded. The exposed wall height was 9 ft and the overall wall height was approximately 19 ft. The steel sheet pile appeared to be PDA27. No other data could be obtained. The observed distresses were dominated by the severe corrosion. Different levels of corrosion were recorded for sections of the wall and included levels 2, 3, 4, and 5. One instance of misalignment with a displacement of 6 in. over 40 ft and one hole 2 ft long by 6 in. wide were also recorded. No other distresses were noted although several experts noted they considered the corrosion to be severe enough to have caused interlock damage and left the steel material so thin that holes were imminent.

Wall D (Figure 9)

62. Wall D is an anchored-type wall approximately 700 ft long that is used as a retaining wall for a parking lot. The exposed wall height was 17 ft and the overall wall height was approximately 28 ft. The steel sheet pile is PZ32. The original anchorage system was battered H-Pile at 4 ft-6 in. centers. When a soil failure occurred at the toe of the wall, a misalignment developed with the bottom of the wall moving out with a displacement of 24 in. over 125 ft. Additional anchor rods were installed at 6 ft centers at a lower elevation to hold this section of wall. The experts were aware of this repair, which may have affected their judgment on the condition index. The experts were not asked to judge the wall as if the repair had not been made. One hole was present and the general state of corrosion was judged to be about Level 2. The experts commented that settlement behind the misalignment might be a problem.

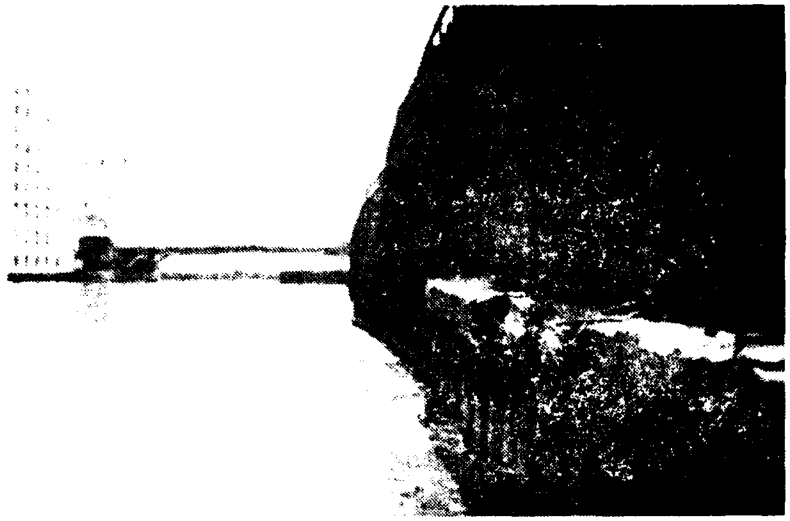


Figure 9. Wall D

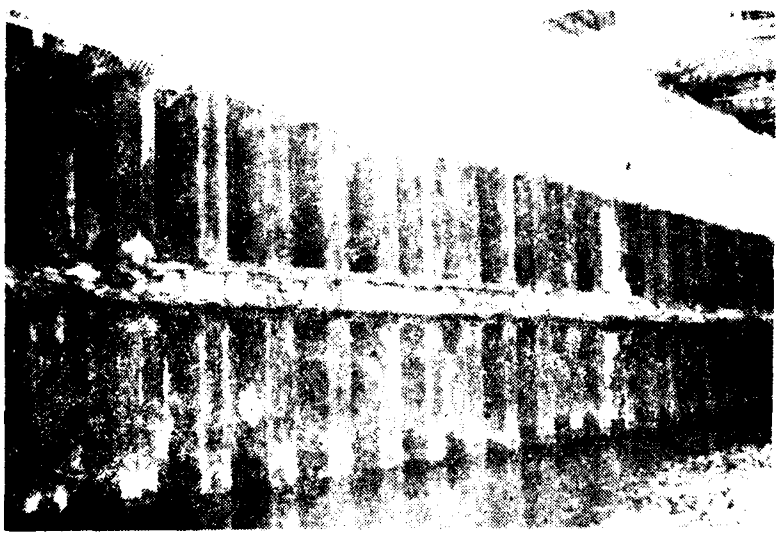


Figure 10. Wall E

Wall E (Figure 10)

63. Wall E is an anchored-type wall approximately 200 ft long used as a retaining wall. The exposed wall height was 11 ft and the overall wall height was approximately 21 ft. Anchor rods appeared to be 1.5 in. in diameter at 7 ft spacings. No other data could be obtained. The observed distresses included four instances of holes about 1 ft across, one crack that was about 2 ft long and separated 1/2 in., and three small dents. A general state of corrosion was judged to be about Level 4. No particular comments were noted by the experts.

Wall F (Figure 11)

64. Wall F is an anchored-type wall approximately 400 ft long used as a loading dock retaining wall. The exposed wall height was 8 ft and the overall wall height was approximately 21 ft. No other data were obtained. The observed distresses included one misalignment with a displacement of 18 in. at the top of the wall over 65 ft of wall, 14 instances of dents that were all in the small category (1 to 2 ft across), and one instance of a crack that was about 2 ft long but not separated. A general state of corrosion was judged to be about Level 2. No other distresses were recorded although the experts noted they considered settlement behind the misalignment and interlock damage and cracks in conjunction with the dents.

Wall G (Figure 11)

65. Wall G was in fact the same wall as Wall F above but the experts were asked to evaluate and rate the wall as if it were a lock guide wall at a lock site.

Thomas J. O'Brien Lock Wall (Figure 12)

66. The lock walls of the O'Brien Lock and Dam facility on the Little Calumet River in South Chicago are cellular SSP structures. The river wall of the lock chamber is 965 ft long and 23 ft wide, composed of diaphragm cells (Figure 4). The land side wall of the lock chamber is similar in construction, but the steel sheet pile is not normally exposed to view so no observation can be made.

67. The exposed sheet pile in the river wall appears to be in reasonably good condition except for two observed distresses. There was a crack in one

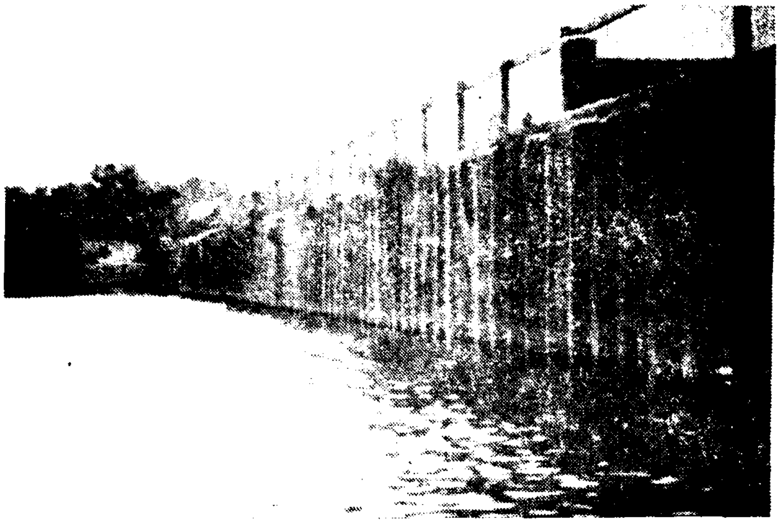


Figure 11. Wall F and G

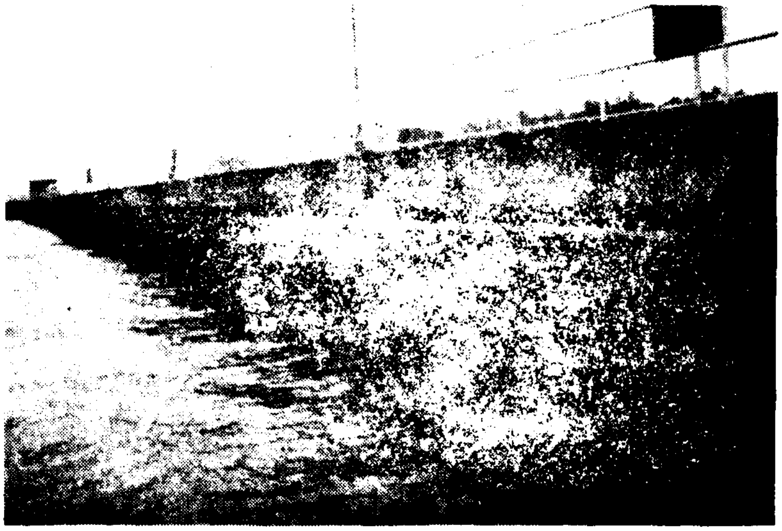


Figure 12. Thomas J. O'Brien lock wall

of the SSP cells running from the top of the cell, down about 5 ft. The concrete cap had settled up to 4 in. near the center of the cells. Little if any settlement had occurred at the cell diaphragms, producing a slightly uneven surface on top of the wall. Corrosion was at a low level.

Thomas J. O'Brien Lower Guide Wall (Figure 13)

68. The lower pool guide wall is an anchored-type wall 1000 ft long used as a retaining wall and for barge alignment with the lock. The exposed wall height was 7 ft and the overall wall height was 24 ft. The anchor rods were 2.5 in. in diameter at 6 ft spacing. The steel sheet pile is PZ27. The only observed distress was a general state of corrosion judged to be about Level 2.

Expert Rating

69. During the field test, each expert was given a copy of the form shown in Table 5 for each wall. As indicated on the form the expert was first asked to estimate the functional condition index for each of the individual distresses listed. The condition rating scale is summarized at the bottom of the sheet and described in somewhat more detail in Part II. The experts viewed each wall and then observed several distresses summarized earlier in this section. The expert was also asked to assign a weight factor (defined in Appendix C) to each distress, considering wall location and function. Finally, an overall wall functional condition index was requested. The results from each expert for each wall are presented graphically in Appendix E.

70. The averages of the experts' ratings for the individual distresses are present in Figures 14 through 21. When these averages were compared to the subjective condition indexes in a previous version of the rating system, several observations were apparent.

a. The previous version tended to overrate the wall. This was corrected by introducing Eq. (C.1) for the functional condition index.

b. No expert gave a condition index of 100. Apparently, the experts judged that no wall could be "perfect" if it had been in existence for several years, even though no particular

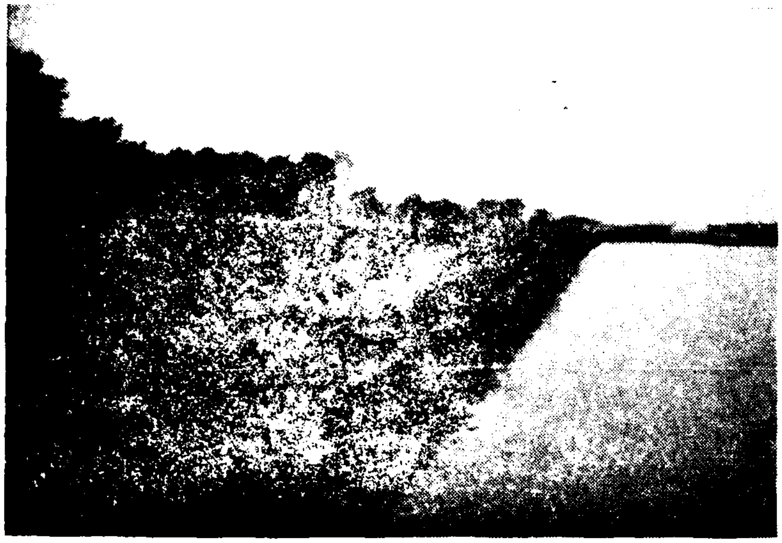


Figure 13. Thomas J. O'Brien lower guide wall

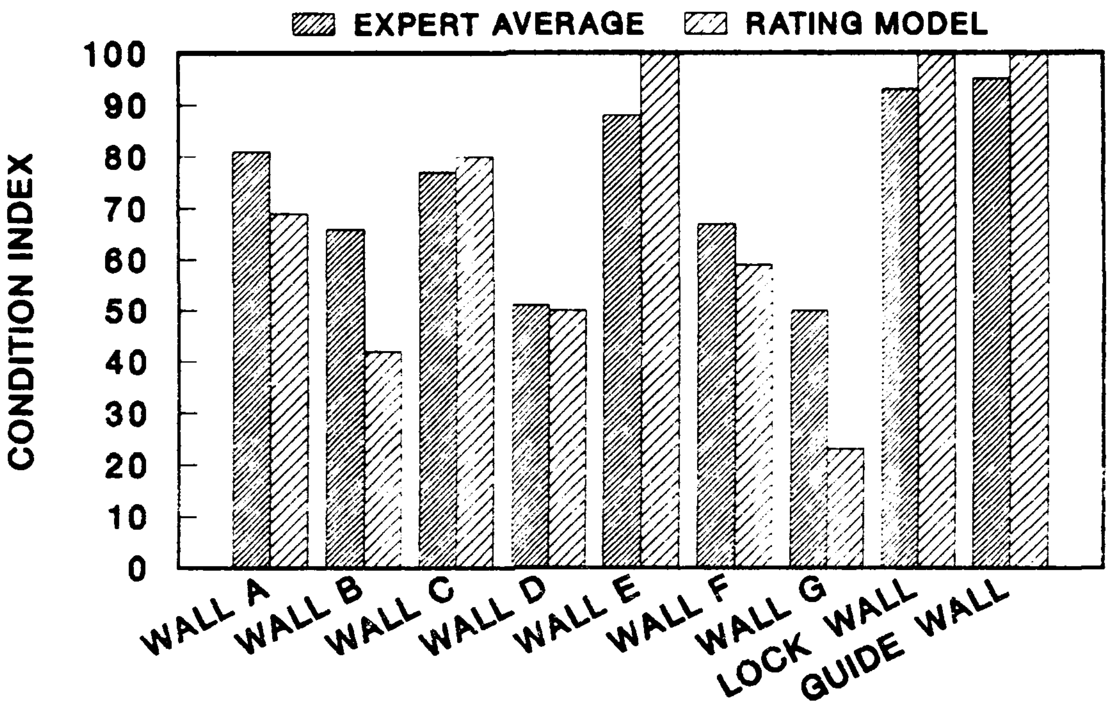


Figure 14. Misalignment rating comparison with experts

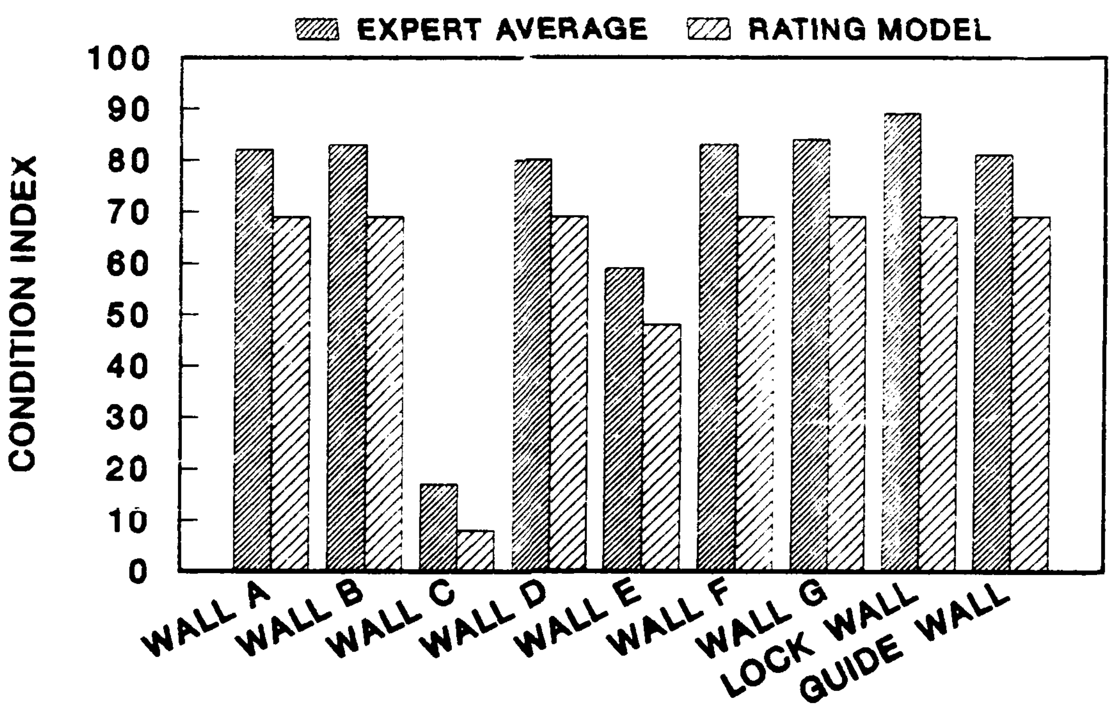


Figure 15. Corrosion rating comparison with experts

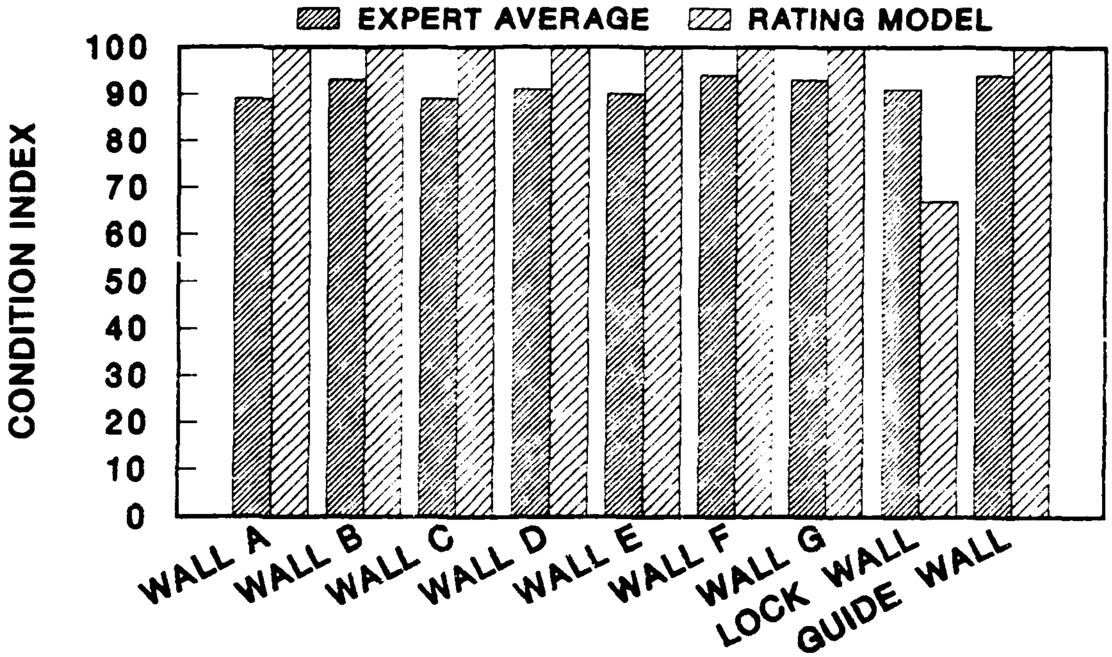


Figure 16. Settlement rating comparison with experts

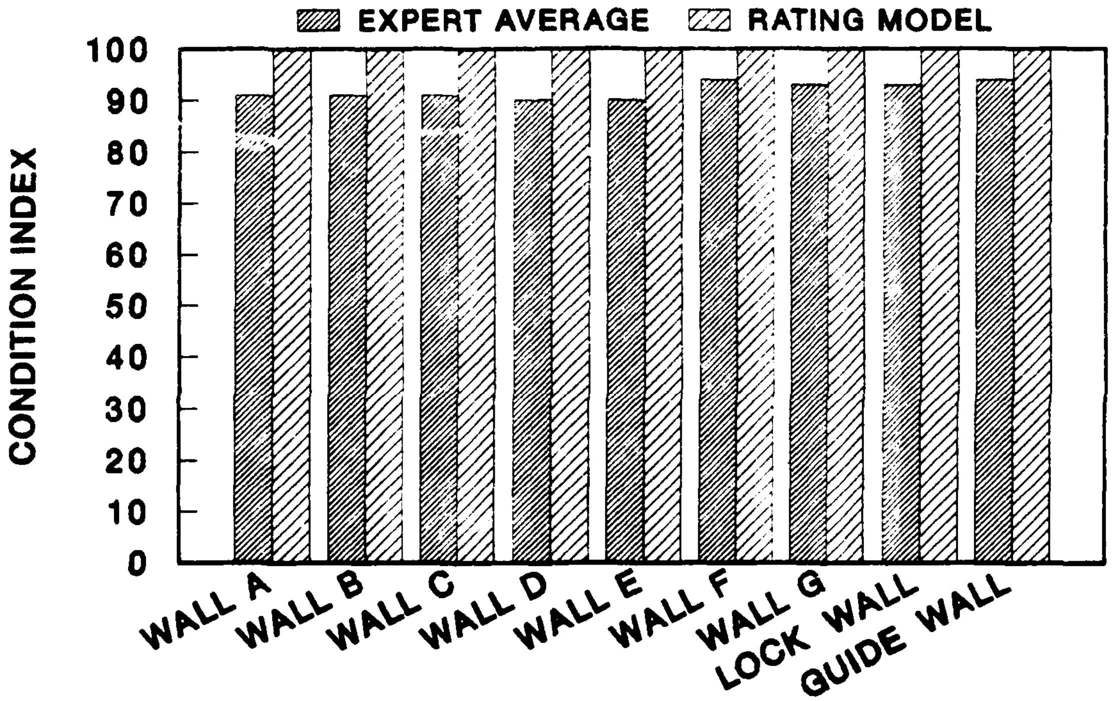


Figure 17. Cavity rating comparison with experts

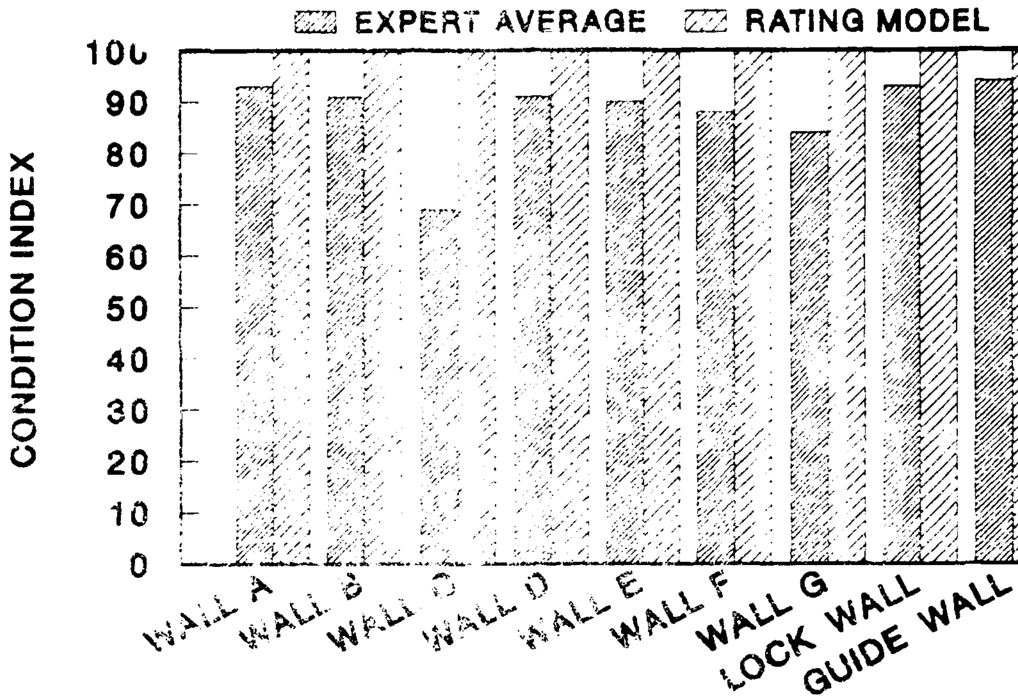


Figure 18. Interlock separation comparison with experts

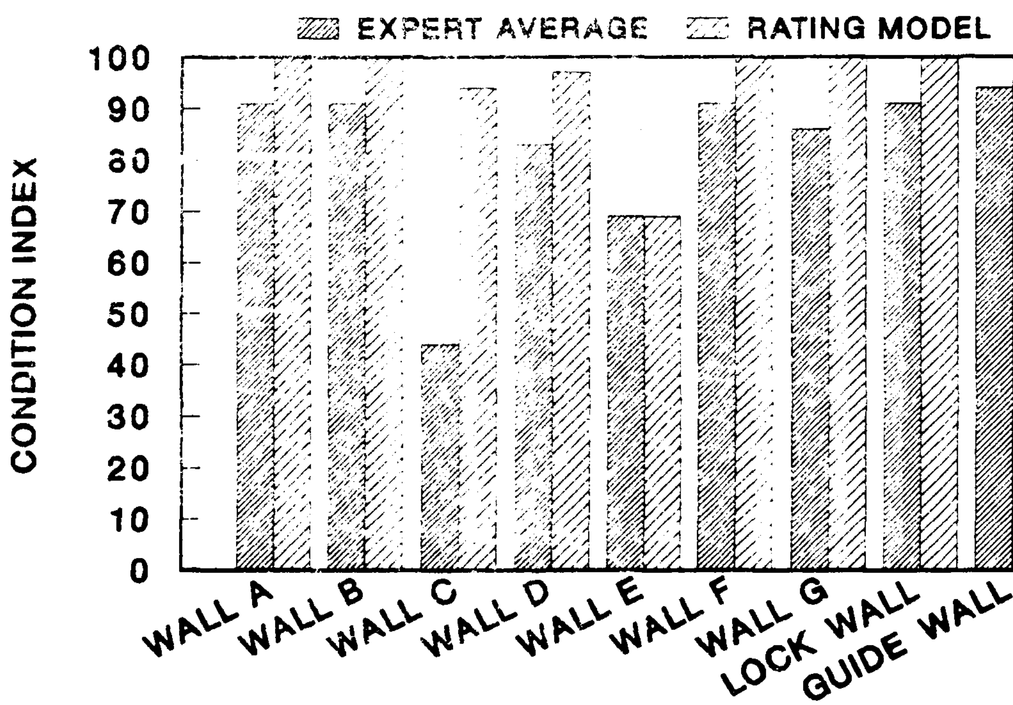


Figure 19. Hole rating comparison with experts

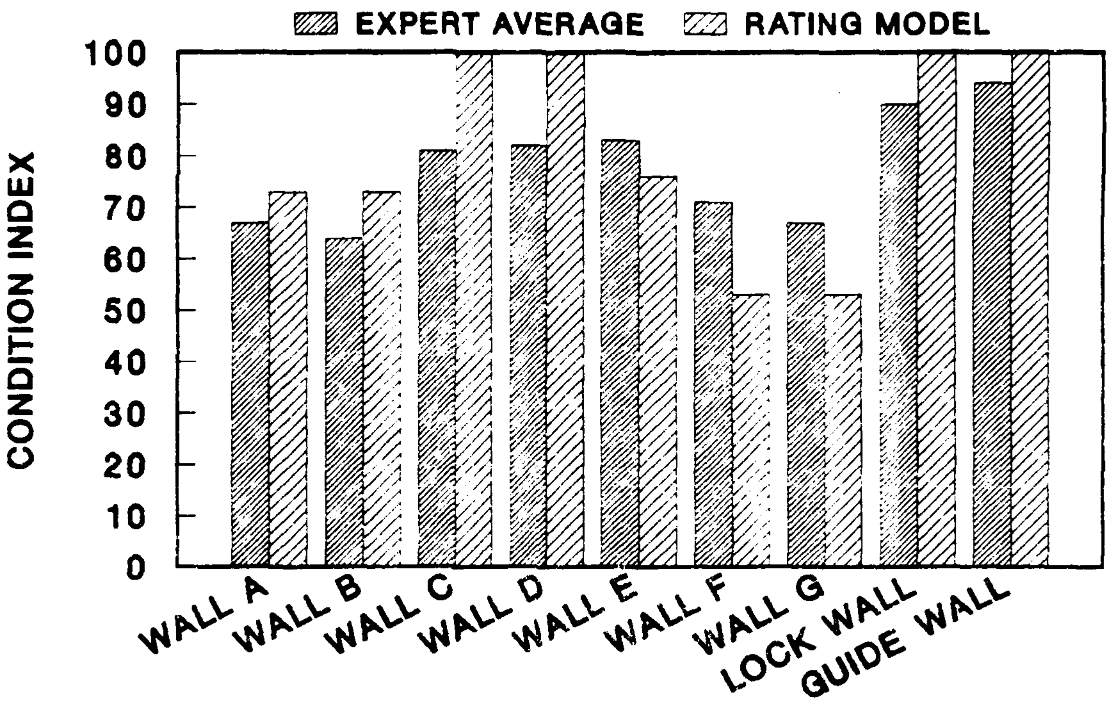


Figure 20. Dent rating comparison with experts

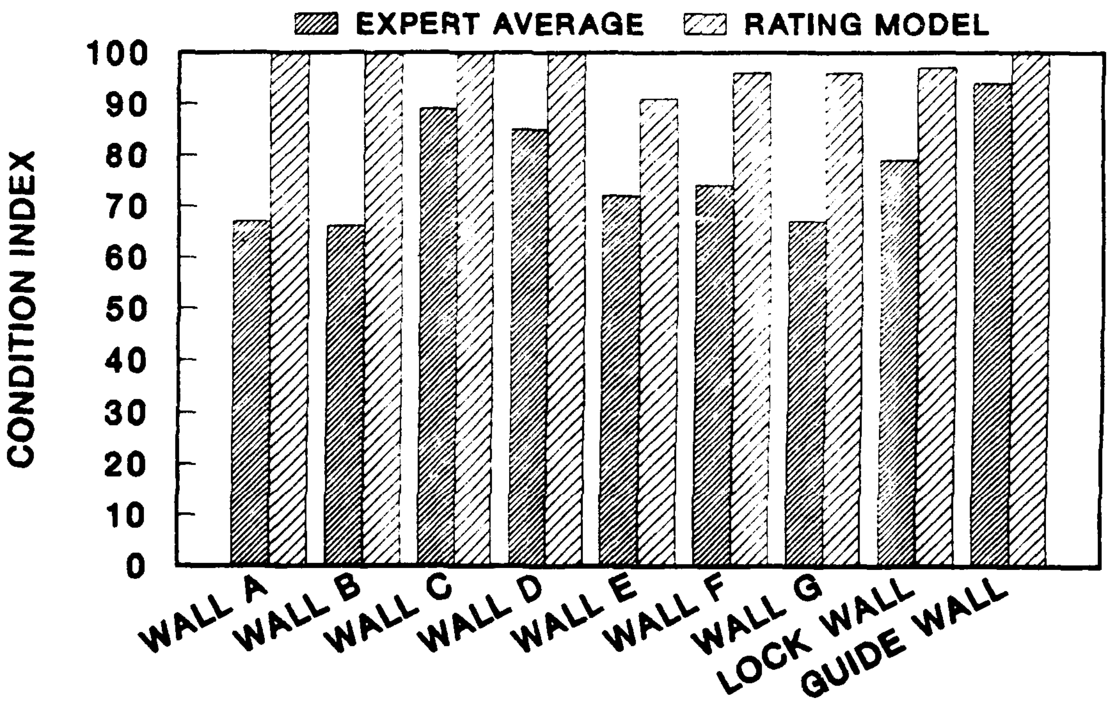


Figure 21. Crack rating comparison with experts

distresses could be documented. No correction was made to the current rating model to reflect this observation.

c. No condition indexes of zero were recorded. Equation (C.1) reflects this change.

With these modifications to the previous version, the walls were re-analyzed using the current version and the resulting individual distress, functional condition indexes are compared to the expert averages in Figures 14 through 21.

71. With regard to the overall wall rating, one observation was very clear--if a wall had a major distress, the overall wall rating was greatly affected. That is, if a distress became severe, its importance was increased. For example, Wall C had a severe corrosion problem. The experts gave the wall a very low overall rating even though they gave corrosion only about a 25% weighting factor. This observation was accounted for by introducing the weight adjustment factor described in Figure C2. The adjustment factor increases the importance of a distress as the distress becomes more severe. A comparison of the experts' average and the overall functional condition index from the current version is summarized in Figure 22.

72. The correct version of the rating system now shows an improved reflection of the experts' subjective rating. As one might expect, however, there is still variance between the current version and the experts and, in fact, between individual experts (Appendix E). The results of any rating must be interpreted in this light.

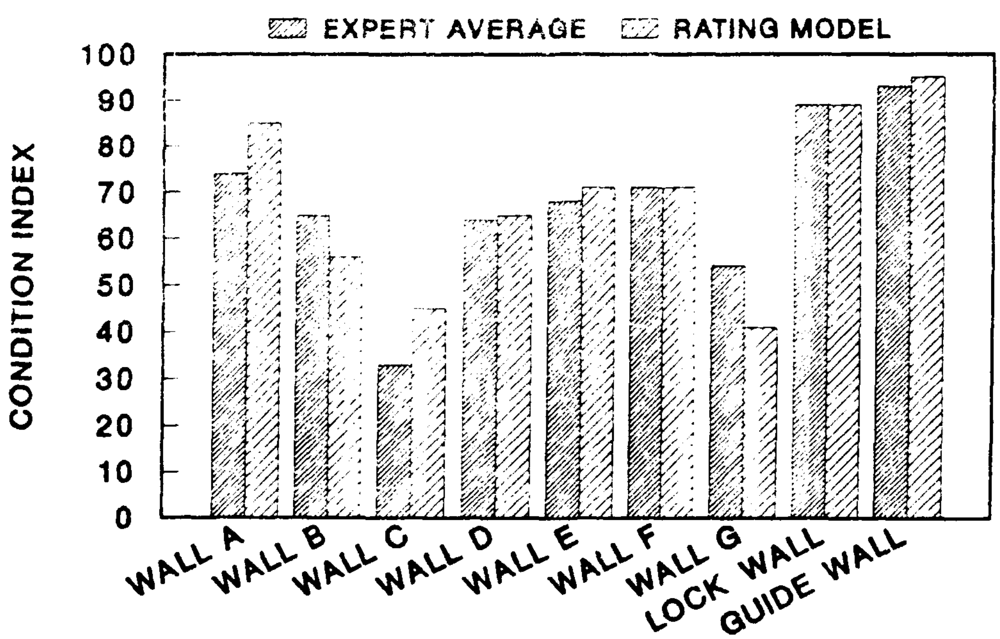


Figure 22. Wall subjective condition index rating comparison with experts

PART V. SUMMARY AND CONCLUSIONS

Summary

73. As a part of the U S Army Corps of Engineers REMR program, a project team at Iowa State University has developed an inspection and rating procedure for steel sheet pile structures. Steel sheet pile anchored, cantilevered and cellular structures serve as lock walls, dams, guide walls, protection structures, and mooring structures.

74. The inspection and rating procedure has intentionally been kept as simple as possible. The inspection requires only simple hand tools such as a tape measure, level, weighted rope, and string. An inspection form has been developed upon which is recorded historical information (location, previous inspections, or repair history, etc.), structural information (wall type, SSP cross section, pile lengths, water depths, dredge line depth, surcharge loadings, etc.) and distress documentation (misalignment, corrosion, settlement interlock separation, etc.). PC software has been written to, first, produce the inspection form and, after the inspection, to record the inspection information on disks.

75. A condition index is computed directly from the inspection records. The condition index is a number scale from zero to 100 that indicates the current state of the structure. It is primarily a planning tool that indicates the relative need to perform REMR work. Condition indexes below 40 indicate that immediate repair is required or, possibly, that a more detailed inspection and re-analysis are required.

76. Two separate condition indexes make up the condition index. The structural condition index is a reasonably objective measure of the structural safety. It is related directly to the factor of safety, which is automatically calculated by the PC software. A functional condition index, based upon the opinion of several experts from the Corps of Engineers, is also calculated. It involves at least two considerations: (1) serviceability, or how the structure performs its function on a day-to-day basis and (2) subjective safety, or how, in the judgment of expert engineers, the safety of the structure has been degraded by various distresses.

77. The inspection and rating procedure has been applied in two field tests (July 1986 and July 1987). The results of these tests have been incorporated into the current version of the procedure.

Conclusions and Recommendations

78. The current inspection and rating procedure for steel sheet pile structures has had sufficient development and testing to warrant its distribution on a wider basis. However, it should still be considered in a state of development. Many of the concepts introduced herein, such as structural condition index, functional condition index, X_{max} values, and weighting factors, should be exposed to a broader range of engineers who work in the area. Modifications to the procedure are certainly expected and welcomed.

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Terzaghi, K., and Peck, R. B. 1948. Soil Mechanics in Engineering Practice, Wiley and Sons.

U.S. Army Corps of Engineers. 1958. Design of Pile Structures and Foundations, Washington, D.C.

United States Steel Corporation. 1972. USS Steel Sheet Piling Design Manual.

Winterkorn, H. F., and Fang, H.-Y. 1975. Foundation Engineering Handbook, Van Nostrand Reinhold.

Table 1

Condition Index Scale

Value	Condition Description
85-100	Excellent--No noticeable defects, some aging or wear may be visible.
70-84	Very Good--Only minor deterioration or defects are evident.
55-69	Good--Some deterioration or defects are evident, function is not impaired.
40-54	Fair--Moderate deterioration, function is not seriously impaired.
25-39	Poor--Serious deterioration in at least some portions of structure, function is seriously impaired.
10-24	Very Poor--Extensive deterioration, barely functional.
0-9	Failed--General failure or failure of a major component, no longer functional.

Table 2

Condition Index Zones

Zone	CI Range	Action
1	70-100	Immediate action is not required.
2	40-69	Economic analysis of repair alternatives is recommended to determine appropriate maintenance action.
3	0-39	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended.

Table 3

Distresses in Steel Sheet Pile Structures

Distress Code	Distress	Brief Description
1	Misalignment	Horizontal or vertical deviation from the design alignment
2	Corrosion	Loss of steel due to interaction with environment
3	Settlement	Vertical movement of material behind sheet pile
4	Cavity formation	Loss of fill material behind or within sheet pile
5	Interlock separation	Failure of sheet interlocks
6	Holes	Broad opening in sheet
7	Dents	Depression in sheet without rupture
8	Cracks	Narrow break in sheet

Table 4

Main Menu

Steel Sheet Pile (SSP)
Main Menu

1. **Create new job files**
2. **Update previously entered files**
3. **Print file contents**
4. **Calculate subjective condition index**
5. **Calculate safety condition index**
6. **Display summary report**
7. **Exit program**

CHOICE:

Table 5

Wall Evaluation Form for SSP Inspection Field Test

WALL EVALUATION FORM FOR SSP INSPECTION FIELD TEST
CHICAGO, IL. **JULY 14 & 15, 1987**

SSP STRUCTURE NAME ________________________________

DISTRESS TYPES AND ESTIMATED CONDITION INDEX

WALL RATING: 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, 0

```
MISALIGNMENT          NO. OF OCCURRENCES ______          WEIGHT FACTOR
100  90   80   70   60   50   40   30   20   10   0
|----|----|----|----|----|----|----|----|----|----|          ______

CORROSION             NO. OF OCCURRENCES ______          WEIGHT FACTOR
100  90   80   70   60   50   40   30   20   10   0
|----|----|----|----|----|----|----|----|----|----|          ______
  CORROSION LEVEL 1___,2___,3___,4___,OR 5___

SETTLEMENT            NO. OF OCCURRENCES ______          WEIGHT FACTOR
100  90   80   70   60   50   40   30   20   10   0
|----|----|----|----|----|----|----|----|----|----|          ______

CAVITY FORMATION      NO. OF OCCURRENCES ______          WEIGHT FACTOR
100  90   80   70   60   50   40   30   20   10   0
|----|----|----|----|----|----|----|----|----|----|          ______

INTERLOCK SEPARATION  NO. OF OCCURRENCES ______          WEIGHT FACTOR
100  90   80   70   60   50   40   30   20   10   0
|----|----|----|----|----|----|----|----|----|----|          ______

HOLES                 NO. OF OCCURRENCES ______          WEIGHT FACTOR
100  90   80   70   60   50   40   30   20   10   0
|----|----|----|----|----|----|----|----|----|----|          ______

DENTS                 NO. OF OCCURRENCES ______          WEIGHT FACTOR
100  90   80   70   60   50   40   30   20   10   0
|----|----|----|----|----|----|----|----|----|----|          ______

CRACKS IN SHEET       NO. OF OCCURRENCES ______          WEIGHT FACTOR
100  90   80   70   60   50   40   30   20   10   0
|----|----|----|----|----|----|----|----|----|----|          ______
```

CONDITION RATING SCALE DESCRIPTION:

90 - 100	EXCELLENT, NO REPAIRS NEEDED
80 - 89	GOOD, SOME AGING AND WEAR NOTICEABLE
70 - 79	GENERALLY GOOD, MINOR DETERIORATION OR DEFECTS ARE EVIDENT
60 - 69	ACCEPTABLE, DETERIORATION & DEFECTS EVIDENT, FUNCTION NOT IMPAIRED
50 - 59	FAIR, MODERATE DETERIORATION, FUNCTION IS SATISFACTORY
40 - 49	MARGINAL, SIGNS OF DISINTEGRATION, FUNCTIONS AT REDUCED EFFICIENCY
30 - 39	POOR, EXTENSIVE DETERIORATION, FUNCTIONAL BUT GREATLY REDUCED EFFICIENCY
20 - 29	VERY POOR, BARELY FUNCTIONAL; NEED IS URGENT FOR ACTION
10 - 19	CRITICAL, GENERAL CONDITION FAILURE
0 - 9	FAILED, BEYOND REASONABLE REPAIR

PROCEDURE:

STEP 1: GENERAL OVERVIEW OF WALL AND IDENTIFY DISTRESSES PRESENT
STEP 2: ASSIGN A CONDITION INDEX TO EACH DISTRESS CATEGORY
STEP 3: ASSIGN A WEIGHT FACTOR % CONSIDERING ALL DISTRESSES, PRESENT OR NOT.
STEP 4: ASSIGN AN OVERALL WALL RATING INDEX TAKING INTO ACCOUNT DISTRESS CI AND WF.

APPENDIX A: BASIC DATA*

Standard Nomenclature System for Sheet Piling

As part of the steel industry's program for unifying and improving the classification and designation of structural steel products, a standardized nomenclatural system for steel sheet piling was adopted in 1972. Principal characteristics of this system are: *simplicity*—using the least number of alphabetic and numerical symbols to specifically identify the given shape and positively distinguish it from all others; and *clarity*—making each designation self-explanatory and completely descriptive.

For the user's convenience, the standard nomenclatural system for steel sheet piling is discussed as follows. The accompanying chart (Table 1) compares *the old with the new designations.*

Alphabetic and Numerical Designations

P	Steel sheet piling
Z	Z-shaped profile or cross-section
S	Straight web profile
SA	Shallow arch profile
MA	Medium arch profile
DA	Deep arch profile
X	High-strength interlock
Number	Weight of sheet piling shape, pounds per sq ft of wall

Example

Steel sheet piling
Straight web
High-strength interlock
Pounds per sq ft of wall

P S X 32

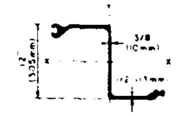
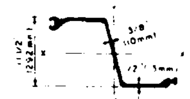
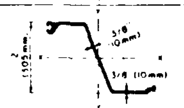
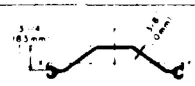
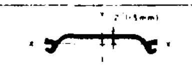
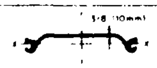
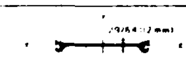
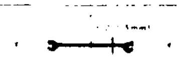
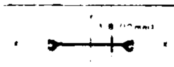
Table 1
Old and New Designations

PROFILE (SHAPE)					
Z		ARCH WEB		STRAIGHT WEB	
Old	New	Old	New	Old	New
MZ 38	PZ38	MP 116	PDA27	MP 103	PSX32
MZ 32	PZ32	MP 115	PMA22	MP 102	PS 32
MZ 27	PZ27	MP 113	PSA28	MP 101	PS 28
		MP 112	PSA23		

Basic Data

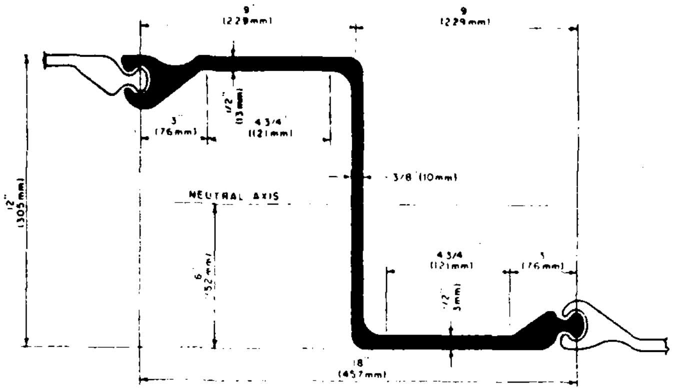
Table 2
Standard Sheet Piling
A General Description

American Engineering Units

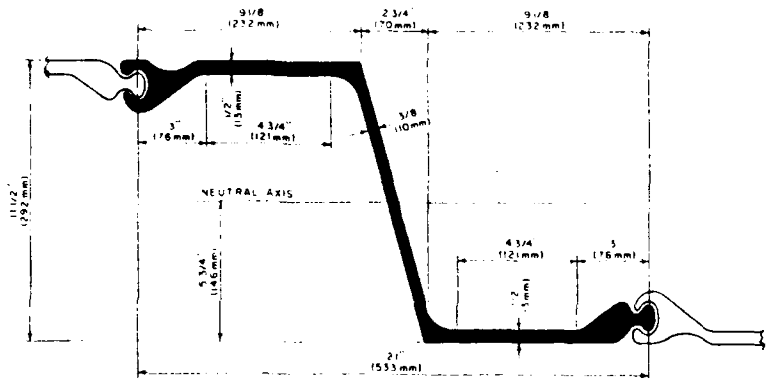
DESIGNATION	PROFILE	INTERLOCK	WEIGHT PER LINEAR FT (LB)	WEIGHT PER SQ FT OF WALL (LB)	AREA A (INCH²)	DRIVING WIDTH (INCH)	SECTION MODULUS PER FT WALL (INCH³)	SECTION MODULUS PER PILE (INCH³)
PZ38		INTERLOCK WITH EACH OTHER AND PSA 23, PSA 28	57.0	38.0	16.8	18	46.8	70.2
PZ32			56.0	32.0	16.5	21	38.3	67.0
PZ27		INTERLOCKS WITH ITSELF AND PSA 23 PSA 28	40.5	27.0	11.9	18	30.2	45.3
PDA27		INTERLOCK WITH EACH OTHER	36.0	27.0	10.6	16	10.7	14.3
PMA22			36.0	22.0	10.6	19 5/8	5.4	8.8
PSA28			37.3	28.0	11.0	16	2.5	3.3
PSA23			30.7	23.0	9.0	16	2.4	3.2
PSX32		INTERLOCK WITH EACH OTHER	44.0	32.0	13.0	16½	2.4	3.3
PS32			40.0	32.0	11.8	15	1.9	2.4
PS28			35.0	28.0	10.3	15	1.9	2.4

Details and Properties

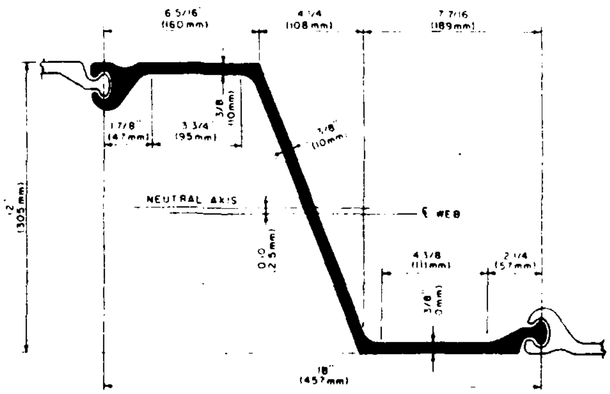
PZ38



PZ32

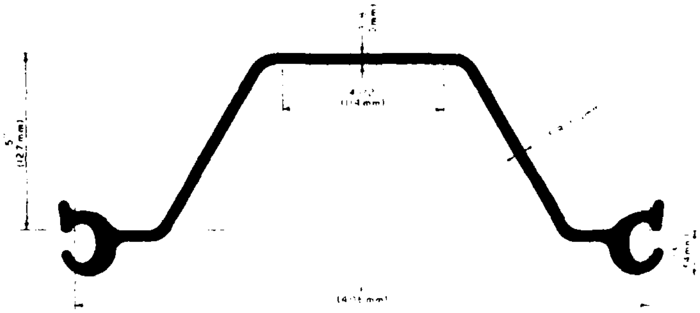


PZ27

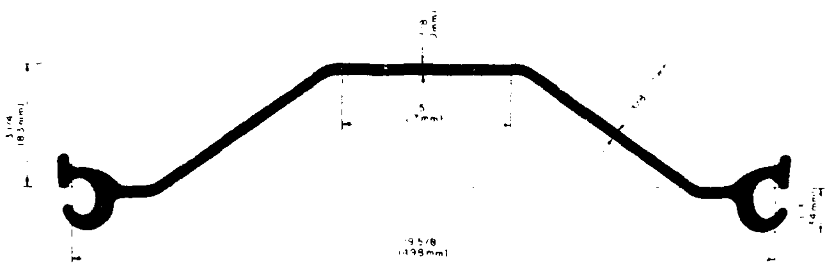


Details and Properties

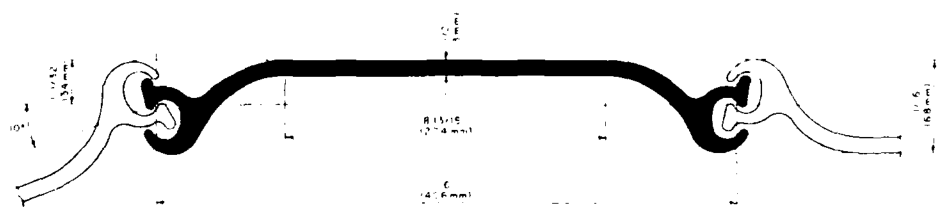
PDA27



PMA22



PSA28



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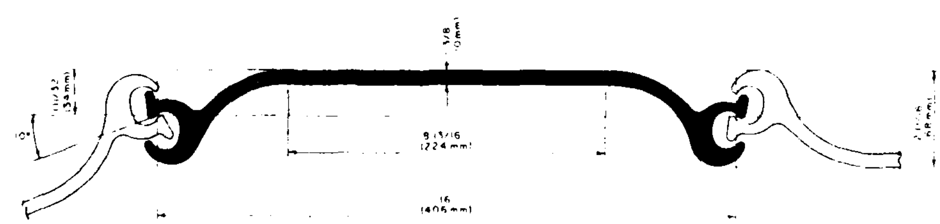
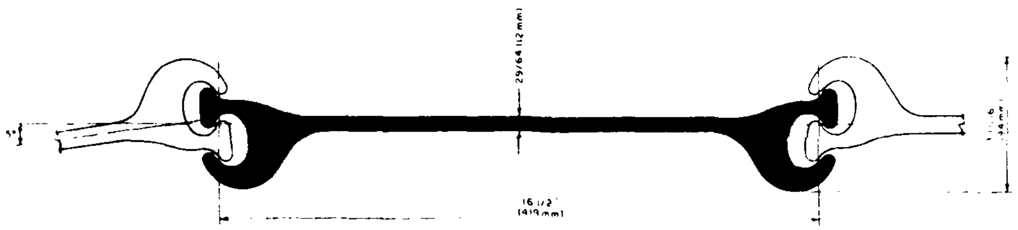


Details and Properties

PSX32



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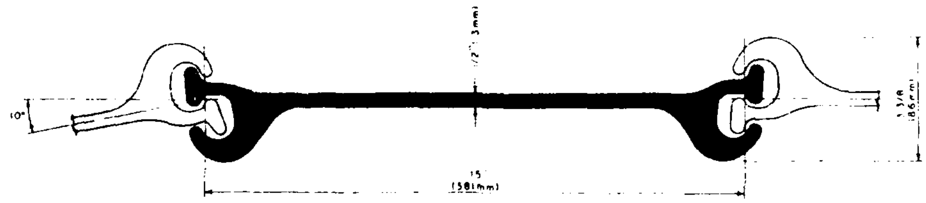

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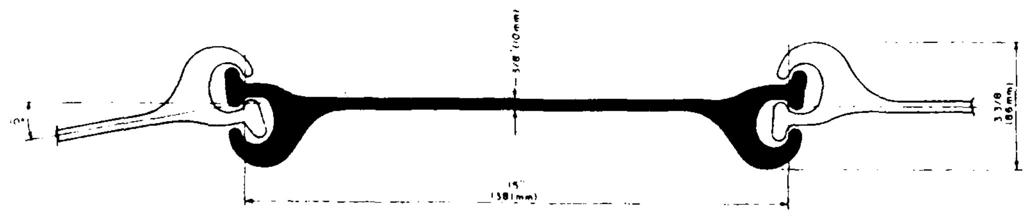


APPENDIX B: STRUCTURAL SAFETY

Structural Analysis

1. A basic part of the structural safety evaluation is a structural analysis. As with all structural analyses, several assumptions must be made. In this work, the basic assumption is that steel sheet piles behave in the manner in which they were designed. With this assumption, the U S Army Corps of Engineer design manual (1958) and the USS Steel Sheet Piling Design Manual (1972) are used for the safety analysis. These sources are supplemented by a U S Corps of Engineering computer program (Dawkins 1981) that implements these rules. In summary, these documents describe how to calculate the active and passive soil pressures on the steel sheet pile by the Coulomb theory.

Cantilever and Anchored Walls

2. For anchored walls, the equivalent beam method is used to calculate the bending moments in the sheet pile and the anchor tension. In the equivalent beam method, the sheet is assumed to act as a statically determinate beam from the top to the inflection point below the dredge line (Figure B1). This inflection point is assumed to occur at the point of zero net soil pressure, that is, passive pressure equal to active pressure. In cantilever wall design, the sheet is embedded to a sufficient depth to behave as a vertical cantilever. With reference to Figure B2, the pile is assumed to rotate about point 0, mobilizing passive pressure above and below the pivot point 0. Equilibrium is satisfied for horizontal forces and moments about any point.

3. Three failure modes are analyzed and three factors of safety are computed:

Pile sheet bending mode

$$FS_1 = F_y/f_b \tag{B.1}$$

Anchor tension mode (anchored wall only)

$$FS_2 = F_y/f_t \tag{B.2}$$

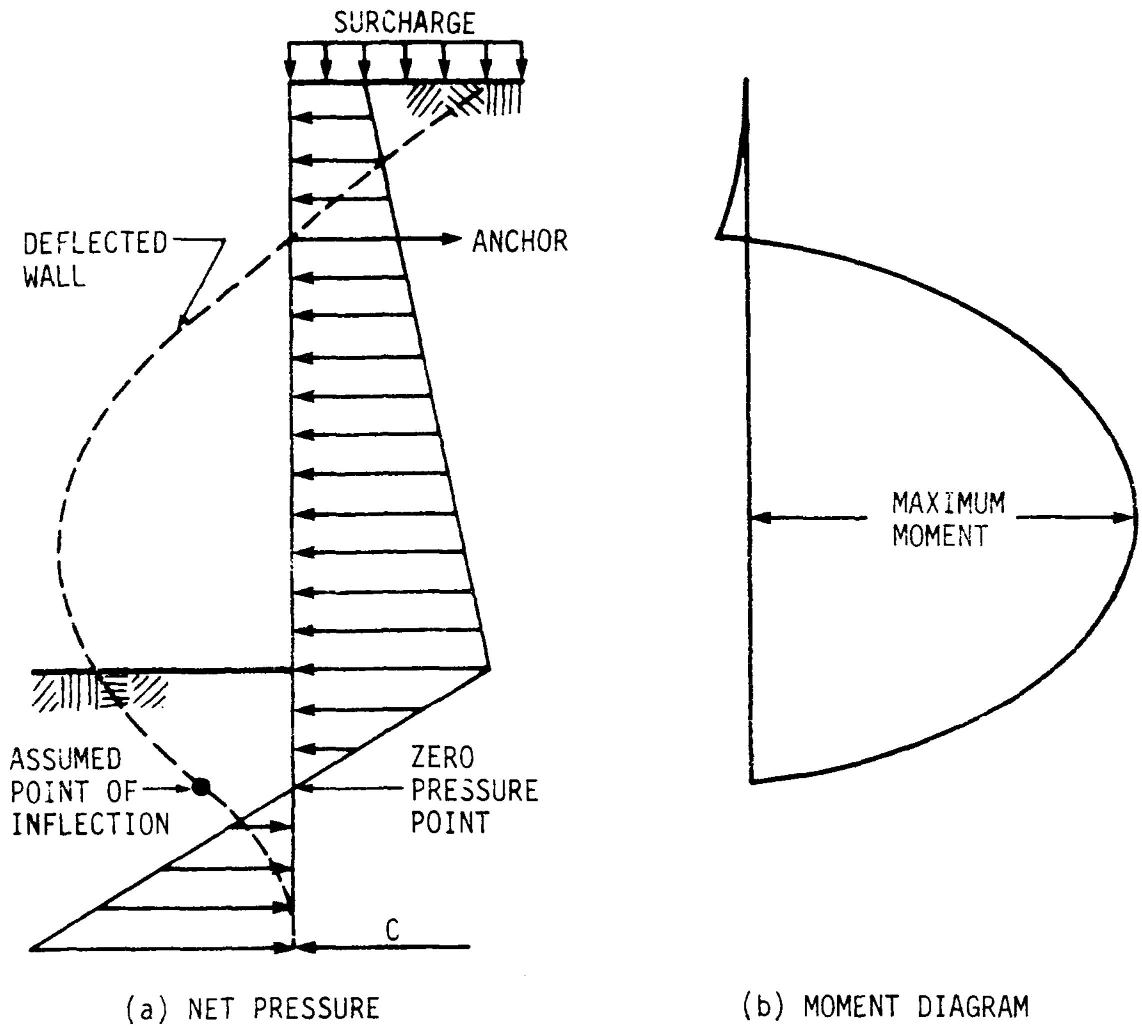


Figure B1. Anchored wall design by equivalent beam method (granular soil)

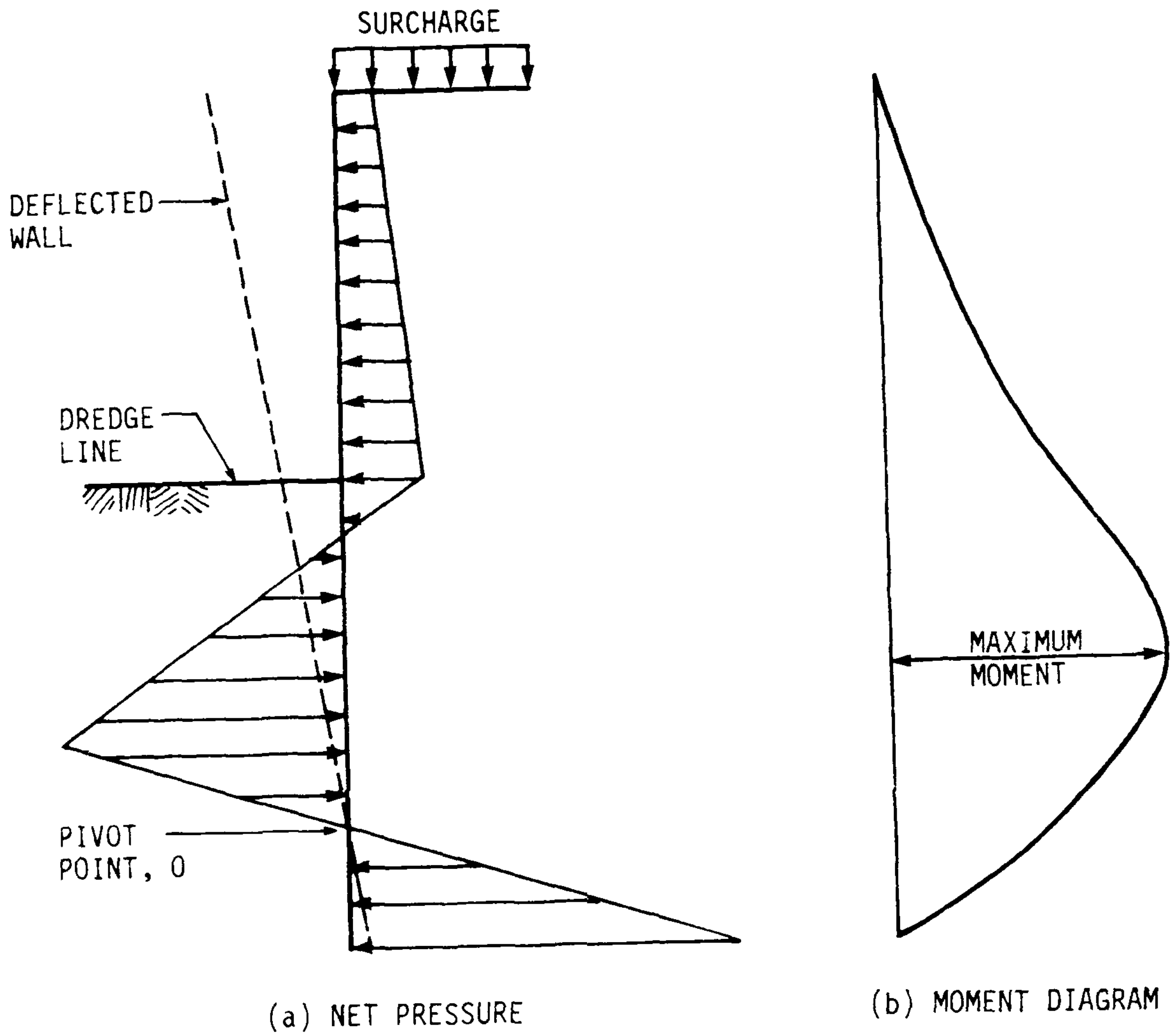


Figure B2. Cantilever wall

4. Soil failure at toe

$$FS_3 = \sigma(c + \tan \phi)/\tau \qquad \text{(B.3)}$$

in which

F_y = steel yield stress

f_b = maximum pile-bending stress

f_t = tensile stress in anchors or bolts

σ = soil normal stress

c = soil cohesive strength

ϕ = soil friction angle

τ = soil shear stress

To limit the program scope to the available time, some failure modes are not analyzed: fixing bolt, wale bending, and anchor system failure. Also, only uniform surcharge loadings are considered.

5. The steel yield strength is requested on the inspection form. If it is not available, it is assumed to be 36,000 psi. The inspection form lists various broad categories of soil descriptions. Table B1 lists the soil properties that are used within this analysis for each of these descriptions. These are approximate values selected by the authors as representative. As discussed in U S Steel (1972, p. 25), the cohesive strength for clays may approach zero for long-term loading. Some suggest that an appropriate assumption for such cases is to take the cohesion equal to zero and a friction angle between 15° and 25°. Others state that this is too conservative (U S Steel 1972, p. 427). In any case, the long term behavior of the soil behind a retaining wall is not well described (U S Army Corps of Engineers 1958, p. 313). For this work, the properties listed in Table B1 will be used. If users wish to use a more conservative assumption, they may enter a weaker soil into the inspection sheet.

6. A computer program has been written to calculate the factors of safety listed above. The program interfaces with the disk prepared with the inspection data. Hence, to calculate the safety of a steel sheet pile structure, one need only respond appropriately to the computer prompts (Table 4). Within each section, the computer selects the worst case in terms of lowest dredge depth or largest loading (page 6 of inspection form). The water level

Table B1

Assumed Properties of Soil

		Unit Weight (PCF)	Friction Angle (ϕ)	Wall Friction (δ)	Cohesion (C) (PSF)
			Short-term Soil Properties		
1.	Sand	90	30	10	0
2.	Gravel	110	35	11	0
3.	Rock	90	45	15	0
4.	Soft clay	95	5	0	400
5.	Medium clay	105	10	3	800
6.	Stiff clay	115	15	5	1500
7.	Unknown	95	5	0	400

is assumed to be the same on both sides of the wall, since the water levels usually change slowly enough to permit equalization of the water level on both sides of the sheet. (This is not assumed for cellular lock walls.) Additionally, the water is conservatively assumed to be at the low water level on page 1 of the inspection sheet. If users wish an analysis at a different water level, they may enter another low water level on page 1 of the inspection sheet.

Cells and Cellular Walls

7. Single cells are designed to resist impact or mooring forces from vessels, while cellular walls are usually designed to resist water and soil pressures. While the applied forces on a single cell are different from those on a cellular wall, the analysis for stability is the same for both. Cellular structures consist of two different materials, steel and soil, which interact in a complex way to resist forces. A totally rational design approach is difficult. Designers rely heavily on past practice and experience. Generally, the design is performed by first establishing the controlling dimensions: the height of the structure, and the low and high water elevations. The design of cellular structures is generally separated into two categories: cellular structures on rock foundation and cellular structures on deep soil deposits.

8. Three different factors of safety associated with three different failure modes are considered for all cellular structures (see Figure B3) (U S Steel 1972):

9. Vertical shear on centerline of cell

$$FS_1 = S_T/Q \tag{B.4}$$

10. Sliding on foundation

$$FS_2 = F_R/F_D \tag{B.5}$$

11. Bursting

$$FS_3 = t_u/t_{max} \tag{B.6}$$

where

S_T = shearing resistance of the cell fill and the interlocks

Q = shearing force per unit length of cellular structure

F_R = horizontal resisting forces

F_D = horizontal driving forces

t_u = minimum ultimate interlock strength

t_{max} = maximum interlock tension

For cellular structures founded on consolidating clay (soft to medium) the foundation failure factor of safety is also considered (U S Steel 1972):

$$FS_4 = 5.7c/\gamma H \tag{B.7}$$

where

γ = unit weight of fill

H = height of cellular structure above ground surface.

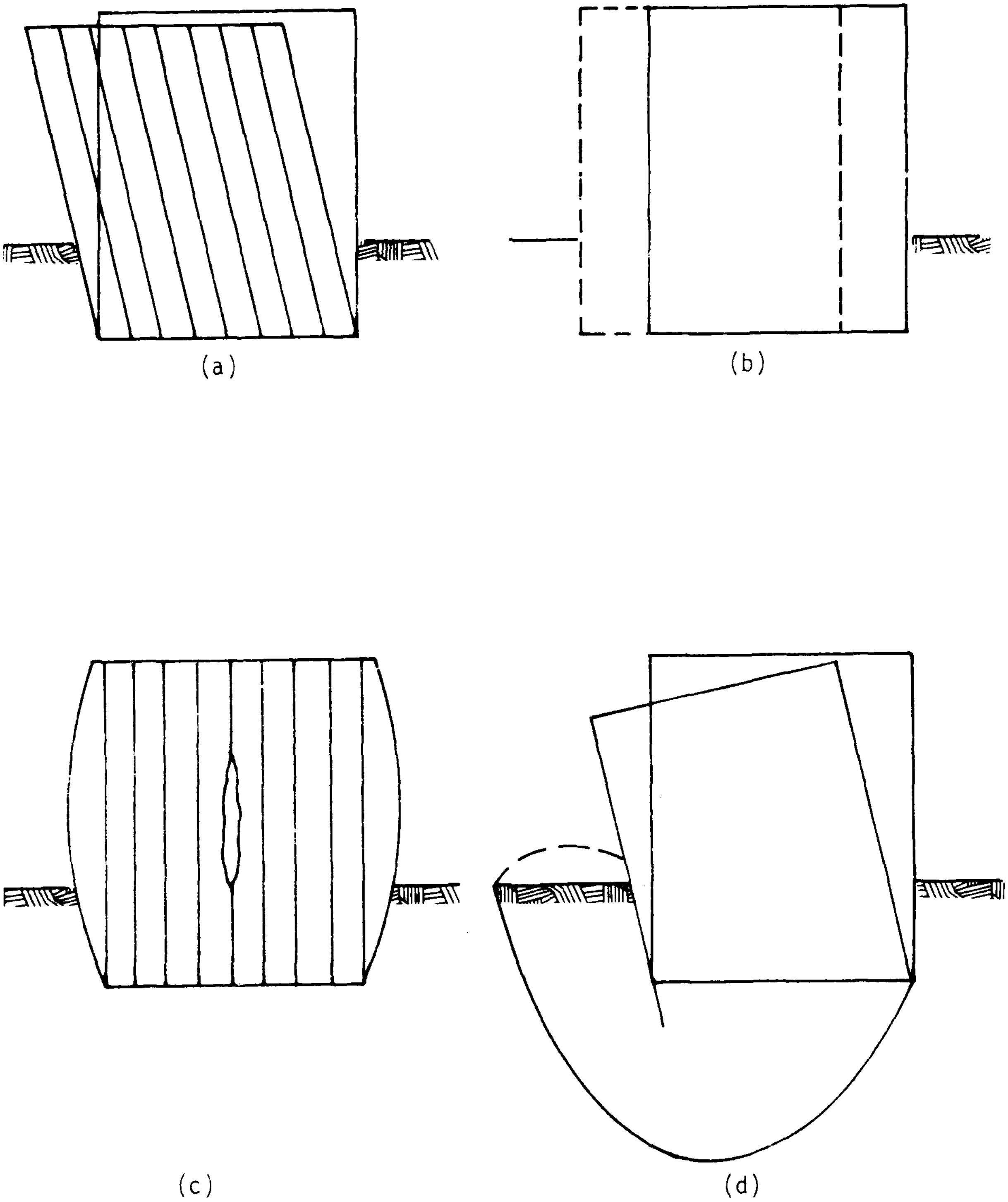


Figure B3. Failure modes for cellular structures:
(a) vertical shear, (b) sliding, (c) bursting,
(d) foundation failure

12. To determine the structural condition index of the cellular structure, the high water level and the low water level that give the worst combination are used to give the lowest factor of safety.

13. For cellular walls, the high water level is assumed to be on the right side of the wall, but not higher than the top of the cell (see Figure B4(a)). The low water level is assumed to be on the left side of the wall. In the case of a lock chamber wall, the low water level is assumed to be at the dredge line.

14. For a single cell, the structural condition index is calculated at both the low and the high water level (not higher than the top of the cell) and the minimum of these two values is used (see Figure B4(b)).

15. In both cases, if users wish to make the analysis for different water elevations, they may do so by changing the low and high water level on page 1 of the inspection form.

Structural Condition Index

16. The factor of safety is related directly to the structural condition index using the condition index zones in Table 2. If the factor of safety is equal to the design value, the condition index is 100. If the factor of safety falls below one, a Zone 3 (condition index less than 40) is indicated. Figure B5 illustrates the two straight lines that are used to relate factor of safety and structural condition index:

$$CI = \begin{cases} 40 \cdot FS & FS < 1 \\ 40 + 60\left(\dfrac{FS - 1}{FS_d - 1}\right) & FS > 1 \end{cases} \tag{B.8}$$

where FS_d is the design factor of safety.

17. As described in the previous section, several factors of safety are calculated, one for each failure mode. The condition index for each mode, CI_i, is calculated using Eq. (B.8). The combined structural condition index for the wall section is found as

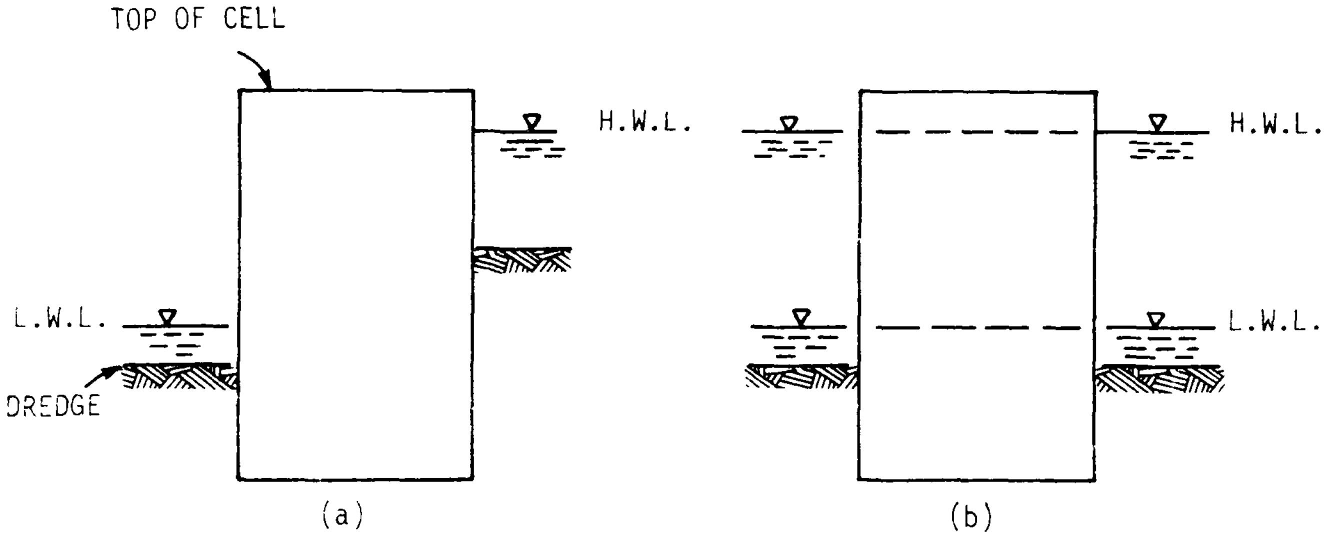


Figure B4. Water level worst case: (a) cellular wall, (b) single cell

$$\text{Structural CI} = \left(\frac{CI_1}{100}\right)\left(\frac{CI_2}{100}\right) \ldots \qquad (B.9)$$

If a wall has more than one subsection, the minimum value from all of the subsections is used.

18. Most distresses (Appendix D) are not included in the calculated structural condition index. However, scour is directly included. Scour is erosion of soil at the toe of the wall caused by water currents. The effect of scour on safety can be dramatic, since the passive soil resistance at the wall toe can be significantly reduced. Actual dredge line elevations from the inspection sheet are used in the safety calculations.

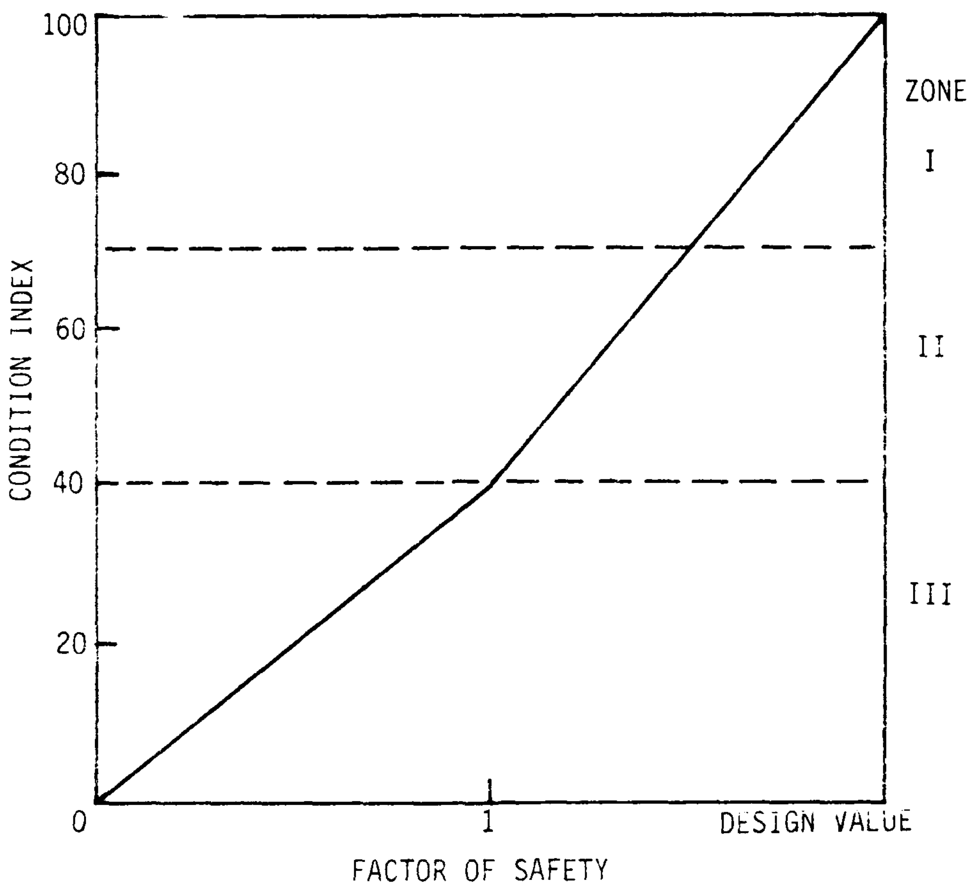


Figure B5. Relationship between factor of safety and structural condition index (Eq. B.8)

APPENDIX C: SERVICEABILITY AND SUBJECTIVE SAFETY

1. As discussed in the section called "Functional Condition Index", a second condition index has been developed that describes more subjective aspects of the rating system, that is, serviceability and subjective safety. The functional condition index is qualified by relating it to X and X_{max}. The quantity X is a measurement of the distress level that is recorded on the inspection sheet. The value of X at which the condition index gives a Zone 3 value (Table 2) is called X_{max}. (See Appendix D for X_{max} values). Several equations and curves have been suggested to relate the ratio X/X_{max} to the functional condition index. The current version of the program uses the equation

$$\text{Functional CI} = 100(0.4)^{X/X_{max}} \tag{C.1}$$

Part IV discusses the correlation of this equation with the collective judgment of Corps engineers for nine walls. Figure C1 illustrates the equation. As defined, the condition index is 40 if X is equal to X_{max}. If X is zero, that is, no distress, the condition index is 100. Note that the functional condition index never quite reaches zero.

2. If there are several occurrences of a single distress type i, the condition index is found as

$$\text{Distress CI}_i = 100\left(\frac{CI}{100}\right)\left(\frac{CI}{100}\right) \ldots \tag{C.2}$$

That is, the functional condition index for distress i is equal to the product of the condition indexes for each individual occurrence of the distress. This equation is used for all distresses except corrosion (see Appendix C).

3. When several types of distress occur, such as both misalignment and settlement, the serviceability condition indexes must be combined into a single value. Weighting factors are introduced to reflect the importance of the various distresses. Hence, let w_i be the weighting factor for the

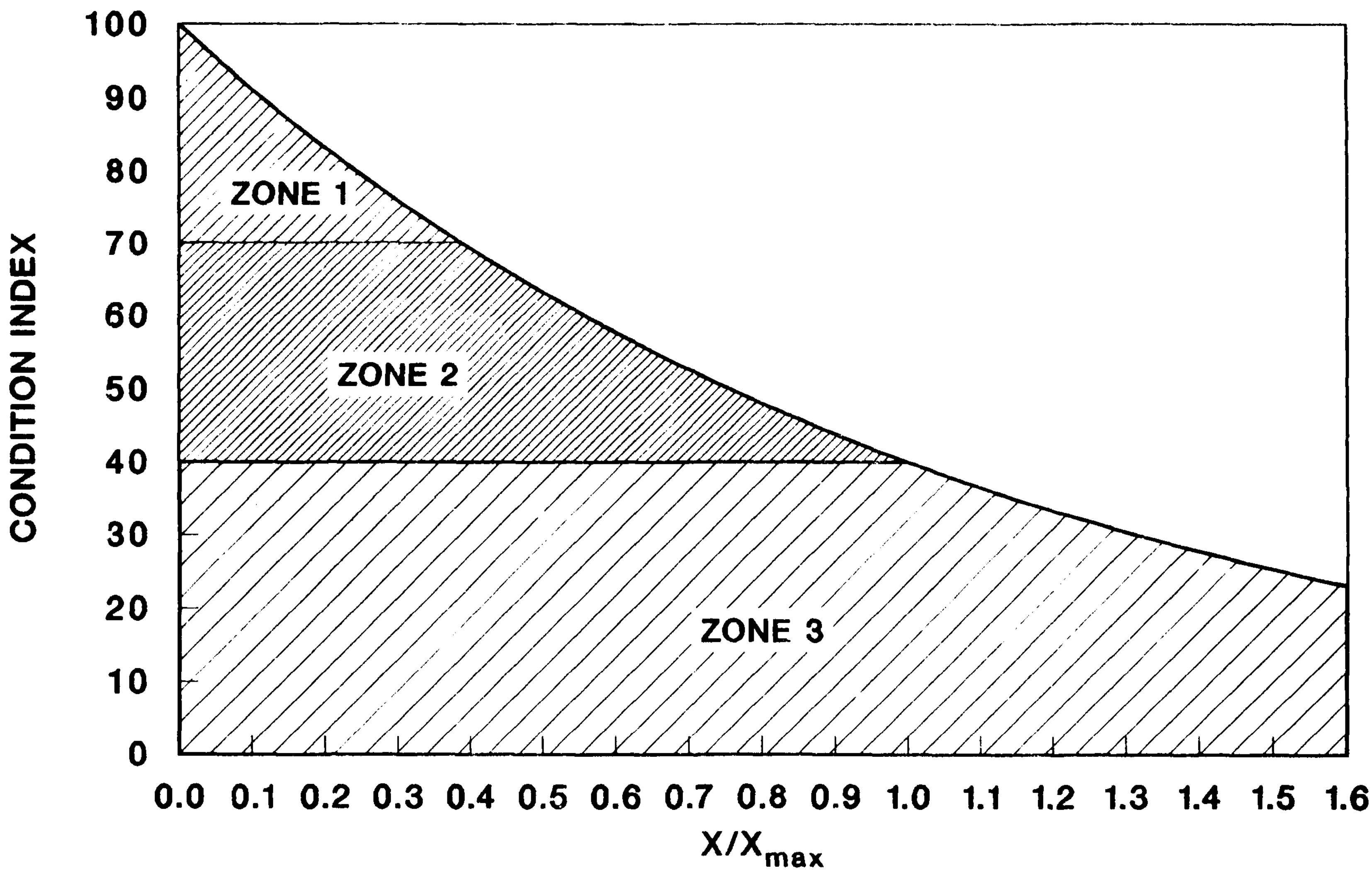


Figure C1. Functional condition index related to X/Xmax (Eq. C.1.)

functional condition index for distress i. For illustration purposes, suppose the weighting factors for three distresses are selected as listed below:

	w_i	W_i (%)
Misalignment	2	50
Settlement	1	25
Corrosion	1	25

This means that misalignment carries twice the weight of corrosion and settlement in the evaluation of the combined functional condition index. The selection of the weighting factors is probably an even more subjective process than the selection of the X_{max} values. Tentative values are proposed within this document for the trial application of this procedure (Appendix D). The normalized weighting factors are defined by

$$W_i = w_i/\Sigma w_i \ (100) \tag{C.3}$$

Note that

$$\Sigma W_i = 100 \tag{C.4}$$

Illustrative values are listed above. The combined functional condition index for all distresses is then given by

$$\text{Functional CI} = W_1 CI_1 + W_2 CI_2 + \ldots \tag{C.5}$$

4. During the field testing of a preliminary version of the above rating procedure, it became clear that, as a distress became more severe, its relative importance became larger. To account for this, a variable adjustment factor was introduced to increase the distress weighting factor as its functional condition index approached Zone 3 (Table 2). The adjustment factor, plotted in Figure C2, has a maximum value of eight; that is, if a distress has a condition index less than 40, its importance increases eight times.

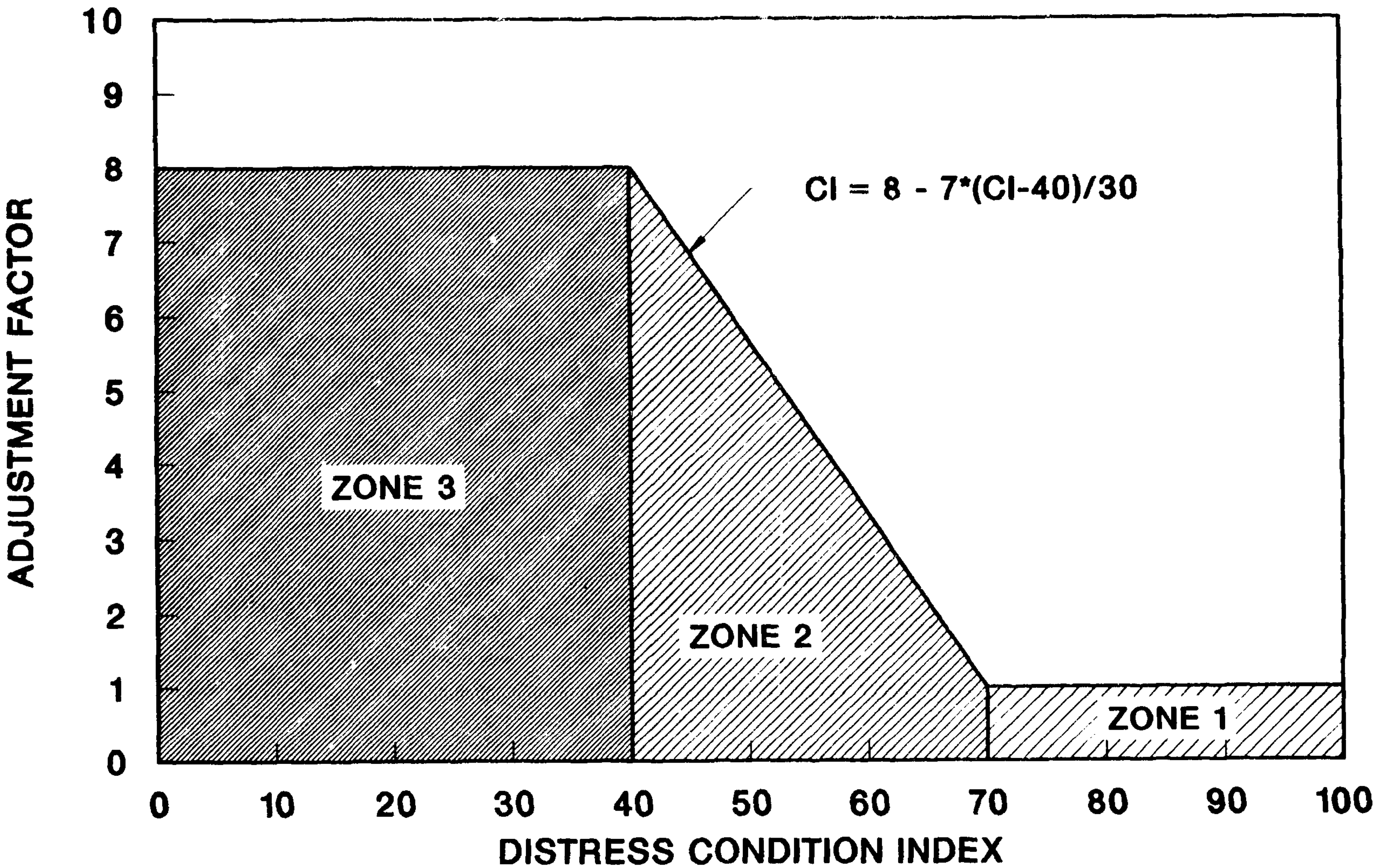


Figure C2. Weight adjustment factor for functional condition index

5. An illustrative example may be helpful. Suppose the following distresses are recorded:

	X	X_{max}	CI (Eq. C.1)
Misalignment	6	12	63
Settlement	2	12	85
Misalignment	4	6	54
Corrosion	3	5	58

Following Eq. (C.2), the functional condition index for misalignment is 100(0.63)(0.54) or 34. The initial weights from above, the adjustment factor from Figure C2, and the revised weights are found as:

	CI	Initial w_i	Adjustment Factor	Revised w_i	Revised W_i (%)
Misalignment	34	2	8.0	16.0	76
Settlement	69	1	1.2	1.2	6
Corrosion	58	1	3.8	3.8	18
				21.0	

The final functional condition index is now found as

$$\text{Functional CI} = 0.76(34) + 0.06(85) + 0.18(58)$$
$$= 41$$

which would put the wall at the dividing point between Zone 2 and 3.

APPENDIX D: DISTRESS DESCRIPTIONS AND X_{max}

1. As discussed in the section called "Condition Index" and in Appendix C, the functional condition index for each distress depends upon the ratio of a field measurement of that distress X to some limit X_{max}. In this appendix, each distress is described including: definition, potential causes, measurement of X, and X_{max} values. In later versions of this work, repair alternatives will be presented. The values of X_{max} are the collective judgment of the authors and several Corps personnel. Again, the X_{max} values correspond to Zone 3 (Table 2); that is, X_{max} represents the value of X at which immediate repair is required or, at least, a detailed inspection and condition re-evaluation are required. Values are presented here on a trial basis for consideration by the initial users of this work. The authors welcome comments. Prior to a field inspection, all distress types should be discussed, with examples and photographs given to assist the inspectors. The distresses are tabulated in Table 3.

Distress Code 1--Misalignment

Definition and Causes

2. Misalignment is a geometric deviation of the sheet pile from its initial design alignment. It usually has both vertical and horizontal components. Misalignment can be caused by several factors (see Figure D1):

a. Structural failure of the sheet, wale, or anchor.

b. Soil falure of the toe or slope.

c. Horizontal sliding.

d. Seepage.

Since misalignment has many causes, its presence may indicate a significant structural problem. As such, misalignment will reduce the experts' subjective opinion of the safety of the structure.

Measurement and Limits

3. Measurement of the displacement will be made at every location where either horizontal or vertical misalignment occurs and exceeds a minimum dimension. The measured dimension will be documented on the profile sheet of the steel sheet pile structure Inspection Form (Figure 5). Documentation of misalignment at each inspection will provide a log of the current conditions

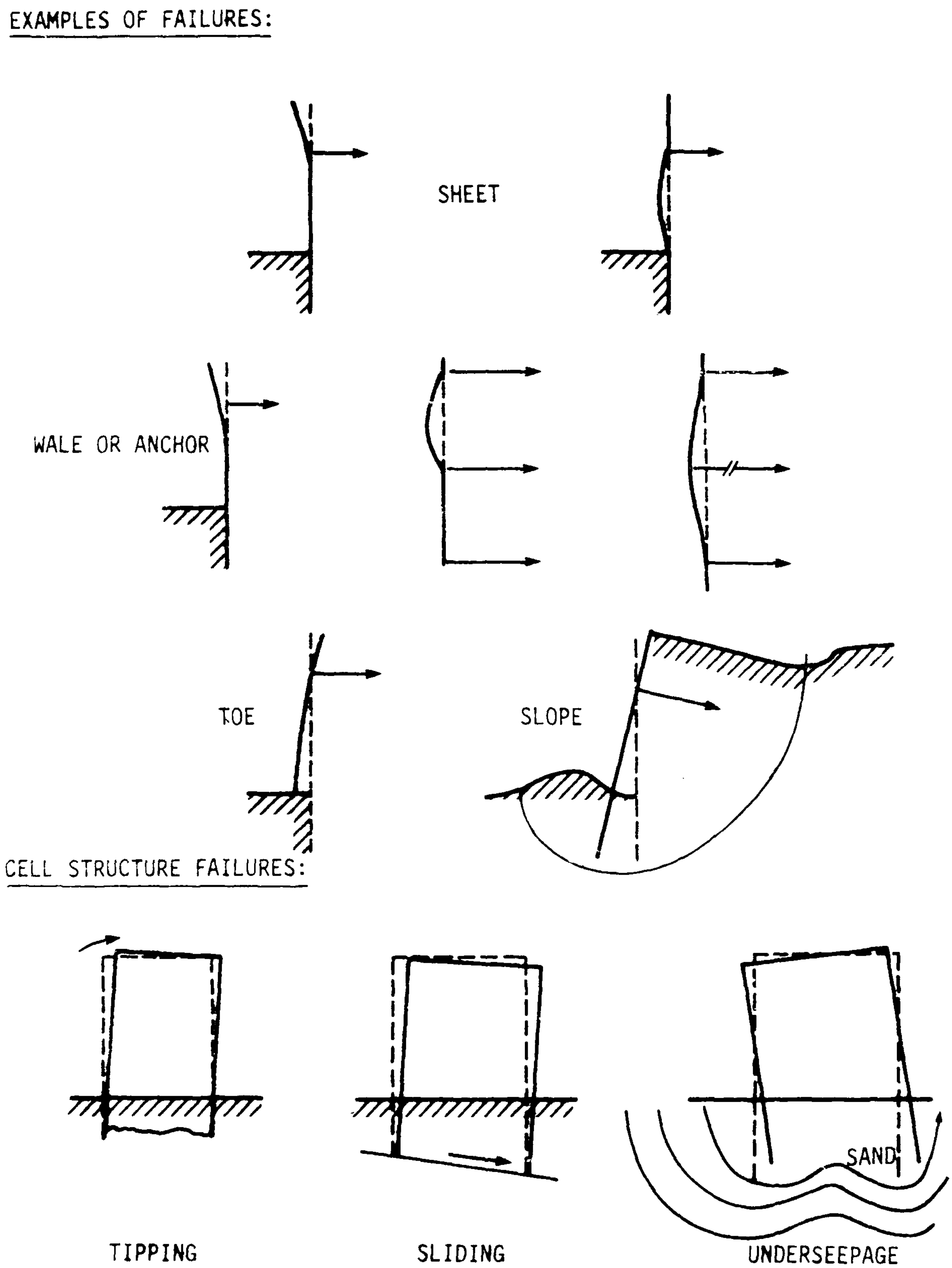


Figure D1. Causes of misalignment

as well as a record for future inspections to determine the rate of deflection. This rate can give information as to the severity of the misalignment problem. The X_{max} values for misalignment for various steel sheet pile structures are listed in Table D1.

Examples

4. a. A lock guide wall 1500 ft long has a bow from 5+00 to 7+00 with the maximum deflection of 8 in. at 6+00 (or 600 ft from the 1200 ft lock chamber). From the formula in Table D1,

$$X_{max} = 6 + 6 \left(\frac{600}{1200}\right) = 9 \text{ in.}$$

and the functional condition index for this case (Eq. C.1) is

$$CI = 100(0.4)^{8/9} = 44$$

5. b. An erosion control wall 3000 ft long and 2 miles upriver from a lock has an 18 in. bow that is 600 ft long. Select 40 in. for X_{max} from Table D1. The functional condition index is

$$CI = 100(0.4)^{18/40} = 66$$

6. c. A cell 40 ft high and 32 ft in diameter is 3 in. out of plumb in 24 in. within the exposed height. It is used for protection in the upper pool. The ratio of cell diameter to height is 32 ft/40 ft or 0.80. Select X_{max} = 4 in. from Table D1. The functional condition index is

$$CI = 100(0.4)^{3/4} = 50$$

Distress Code 2--Corrosion

Definition and Cause

7. Corrosion is the loss of the steel material in the sheet pile due to interaction with its environment. The rate of corrosion is dependent upon

Table D1

X_{max} Values for Misalignment

WALLS

Length of Misalignment (ft)	Lock Chamber (in.)	Lock Guide Wall (in.)	Transition Wall or Retaining Wall or Guard Walls	
			Near Lock (in.)	Remote (in.)
0 to 20	6	Formula below	12	18
20 to 100	6	"	18	24
100 to 500	6	"	24	32
> 500	6	"	24	40

Formula for Lock Guide Wall:

$$X_{max} = 6 + 6\left(\frac{\text{distance from lock}}{\text{length of lock chamber}}\right)\text{ in.}$$

SINGLE CELLS

Ratio of Cell Diam./Height*	Misalignment (in./2 ft of height)			
	Upper Pool		Lower Pool	
	Protection Cell	Mooring Cell	Protection Cell	Mooring Cell
>0.75	4	2	2	1
0.5 - 0.75	3	1.5	1.5	1
<0.50	2	1	1	0.67

*Height is distance from top of cell to dredge.

the oxygen concentration and moisture in contact with the steel. A steel sheet pile structure is exposed to different zones of corrosion (Figure D2). While corrosion is usually very evident and easily noticed in the exposed areas, it is the concealed components that are of most concern for safety reasons, that is, those well below the water surface.

Measurement and Limits

8. The effect of corrosion in the atmospheric and splash zones is used to evaluate the functional condition index because it is visible there. A distress coefficient for corrosion must take into account that corrosion of a steel sheet pile structure can seldom impede the successful or smooth operation of the structure. However, a corroded structure of some age is not in as good a condition as a new structure. Its safety has been reduced. The effect is a subjective evaluation of safety that is difficult to quantify by measurements or testing. One way to evaluate the corrosion of a structure is to set a series of standards, or levels of corrosion, with corresponding numeric distress coefficients. The base for such an evaluation standard would be new steel sheet pile or clean and painted steel sheet pile with no scale or pitting. The various levels of corrosion are described in Table D2 and illustrated in the associated photographs in Figure D3. If more than one level of corrosion is recorded for a wall, the corrosion condition index is obtained as the length times the weighted average.

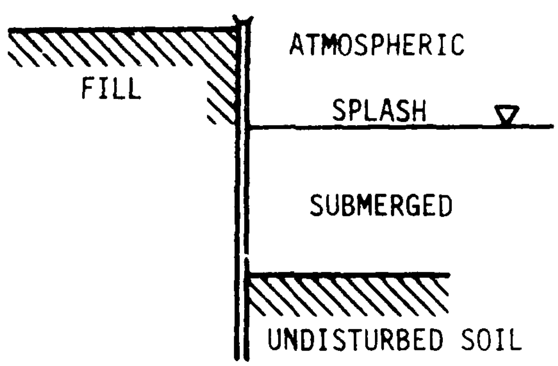


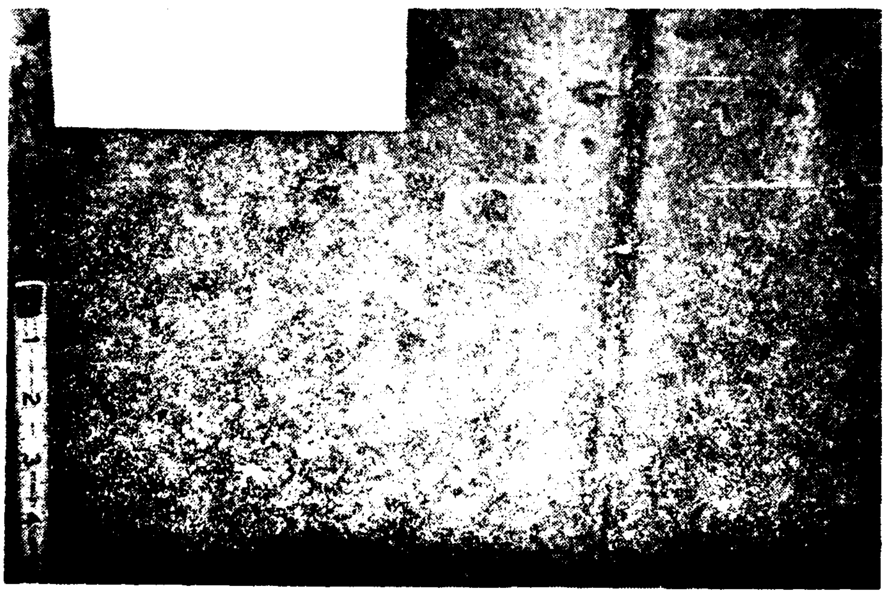
Figure D2. Zones of corrosion

Table D2

Levels of Corrosion*

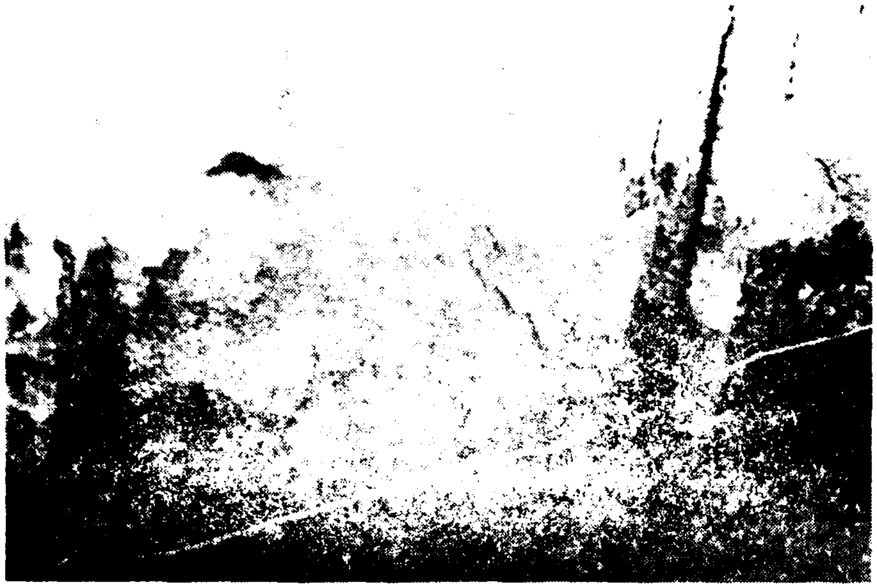
Level	Description
0	New condition
1	Minor surface scale or widely scattered small pits
2	Considerable surface scale and/or moderate pitting
3	Severe pitting in dense pattern, thickness reduction in local areas
4	Obvious uniform thickness reduction
5	Holes due to thickness reduction and general thickness reduction

*Refer also to Figure D3.

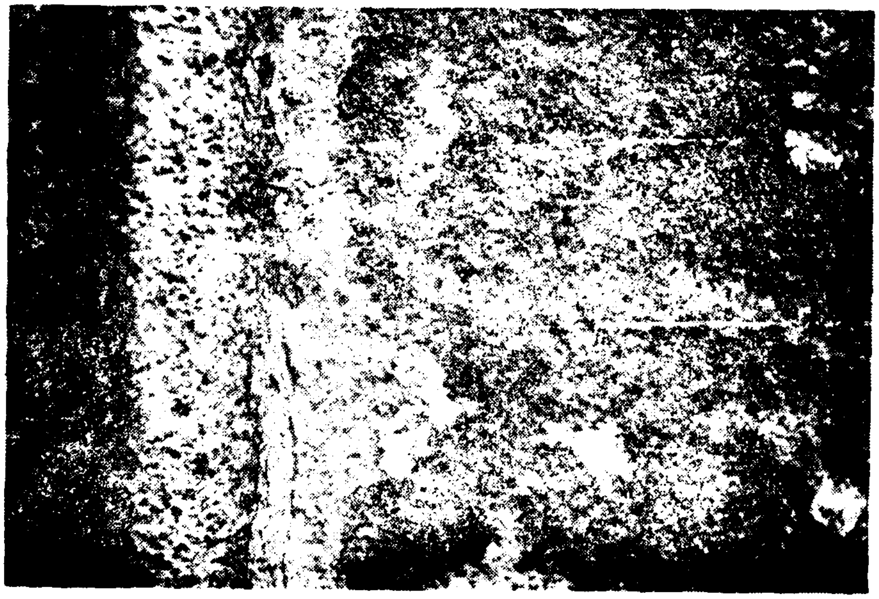


(a) LEVEL 1: MINOR SURFACE SCALE OR WIDELY SCATTERED SMALL PITS

Figure D3. **Photos of levels of corrosion in atmospheric zone** (Sheet 1 of 3)

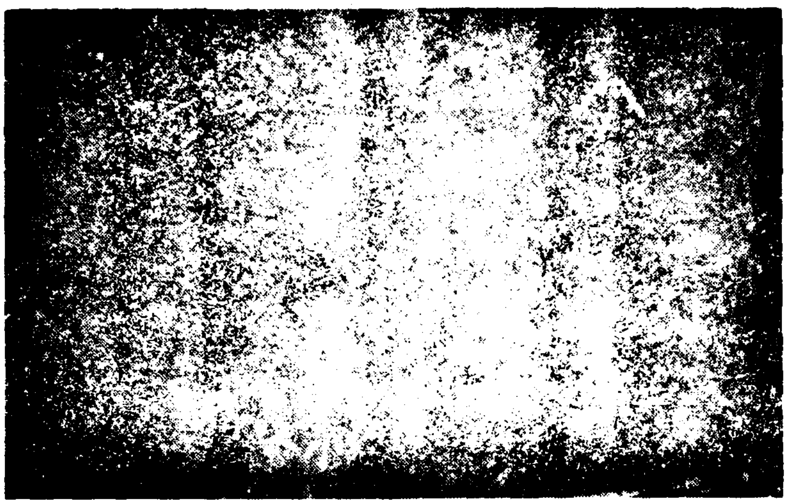


(b) LEVEL 2: CONSIDERABLE SURFACE SCALE AND/ OR MODERATE PITTING



(c) LEVEL 3: SEVERE PITTING IN DENSE PATTERN, THICKNESS REDUCTION IN LOCAL AREAS.

Figure D3. (Sheet 2 of 3)



(d) LEVEL 4:OBVIOUS UNIFORM THICKNESS REDUCTION

(e) LEVEL 5:HOLES DUE TO THICKNESS REDUCTION AND GENERAL THICKNESS REDUCTION

Figure D3. (Sheet 3 of 3)

Example

9. A 600-ft steel sheet pile wall has a corrosion level of 1 over 500 ft and a corrosion level of 3 over 100 ft. The functional condition index for the 500 ft length is calculated as

$$CI = 100(0.4)^{1/5} = 83$$

and for the 100 ft length as

$$CI = 100(0.4)^{3/5} = 58$$

so that the final corrosion functional condition index is

$$CI = 83\left(\frac{500}{600}\right) + 58\left(\frac{100}{600}\right) = 79$$

Distress Code 3--Settlement

Definition and Cause

10. Settlement is the vertical movement of the soil behind the sheet pile. It can be caused by consolidation of the soil, loss of backfill, or wall movement. Settlement can affect operation behind the wall. In cells it can indicate a partial loss of strength, that is, a subjective reduction in safety.

Measurement and Limits

11. Measurement will be made at every location where settlement occurs and exceeds a minimum dimension. The measurements must note the location of the depression on the profile sheet. The settlement depth is recorded and used to calculate the functional condition index. Additional documentation of the width behind the structure is also recorded. The X_{max} limits for settlement are listed in Table D3.

Examples

12. a. A lock guide wall (cantilevered, anchored, or cellular) is 1500 ft long and has no surfacing behind the wall. A depression 27 in. deep by

Table D3

Maximum Limits for Settlement

WALLS (anchored, cantilevered, and cellular)

Length of Settlement & Surface Cond.	At Lock Chamber (in.)	Near Lock (in.)	Remote (>1000 ft) (in.)
Supporting a structure	4	6	6
<20 ft & hard surfaced	4	12	18
>20 ft & hard surfaced	4	18	24
<20 ft & no surfacing	4	24	36
>20 ft & no surfacing	4	36	48

BACKFILL WITHIN SINGLE CELLS

Rule 1: For uniform settlement (from top of structure or design level)

X_{max} = 1/2 in. allowable increment per 1 ft of cell height

Rule 2: For differential settlement (slopes across top surface or the cap if tilted from level)

X_{max} = 3 in. slope per 10 ft diameter

35 ft long occurs behind the wall at 800 ft from the lock. From Table D3, select X_{max} = 36 in. and find the functional condition index as

$$CI = 100(0.4)^{27/36} = 50$$

13. b. A single cell has a 42 ft diameter and is 24 ft tall. If a uniform settlement of 5 in. occurs, the functional condition index is

$$CI = 100(0.4)^{5/12} = 68$$

If a differential settlement of 5 in. occurs,

$$CI = 100(0.4)^{5/(4.2)(3)} = 70$$

Distress Code 4--Cavity Formation

Definition and Cause

14. Cavity formation occurs behind the sheet when some of the fill material is lost. Associated settlement may or may not occur, but a potential for settlement does exist. The material may be lost through a hole in the sheet or beneath the sheets. The loss of fill material could obstruct navigation, damage underground utilities, and reduce strength.

Measurement and Limits

15. A cavity behind a sheet is recorded during the inspection by measuring its size: depth, length, height. Its location (station) will also be recorded. The volume of the cavity is used as the measure of its effect on functional condition index. The limiting values are listed as Table D4.

Example

16. A cavity is found under the concrete cap on a single cell. The approximate dimensions of the cavity are 2 ft wide × 18 in. × 10 in. high.

$$X = (2)(1.5)(0.83) = 2.49 \text{ ft}^3$$

Table D4

Maximum Volume Limits for Cavities

Above Grade Surfacing Condition	Walls (ft^3)	Cells (ft^3)
No surfacing	27	16
Surfacing	8	8
Supported structure	3.5	3.5

$$CI = 100(0.4)^{2.5/8} = 75$$

Distress Codes 5-8:

5. Interlock Separation
6. Holes
7. Dents
8. Cracks

Definition and Cause

17. These four distresses represent openings in the steel sheet. They can be caused by several factors but usually are caused by impact or corrosion. Large, major holes due to impact will, most likely, be fixed very shortly after they occur. Generally, they will not be present at an inspection and are, therefore, not included.

18. These four distresses are grouped together in terms of their consideration for service loss and safety to the steel sheet pile structure. In general, there is no significant loss or impedance to operation of the structure. However, as is the situation with corrosion, the occurrence of these distresses does cause the steel sheet pile structure to be in a less than design condition. Subjectively, the safety has been reduced though it may be difficult to quantify in an analytical manner. These distresses may contribute in a direct manner to the presence of other primary distresses, such as settlement, which have safety and serviceability consequences. In this case,

the effect of the opening is also accounted for in the primary distress condition index.

Measurement and Limits

19. The sizes of all significant separations, holes, dents, or cracks are recorded. Openings below a certain size are ignored, for example, bolt holes or lifting holes.

20. For each singular occurrence of any of these distresses, little effect would be noticed on serviceability. However, the cumulative effect of five of these distresses would be significant if they occurred in, say, 100 ft of steel sheet pile structure. Therefore, the X_{max} limits for openings are defined in a slightly different manner than other distresses. No size limits are explicitly defined, that is, how big or long is the distress. Rather, notes are made of one occurrence of an interlock separation, a hole, a dent, or a crack. Dimensions for each are recorded on the profile sheet. The density of the holes per given length of structure is defined as X. An X_{max} of 5 holes/100 ft is selected, that is, 5 or more holes per 100 ft is a Zone 3 condition.

Example

21. If 10 holes are recorded in a 700 ft wall, X is equal to 10/7 holes per 100 ft and the functional condition index would be

$$CI = 100(0.4)^{10/(7)(5)} = 77$$

Weighting Factors

22. As discussed in Appendix C, par. 1, the functional condition index for the entire wall is a linear combination of the distress subjective CI times weighting factors (Eq. C.5). The initial weighting factors assign more value to the more significant distresses. Relative and normalized initial weights are listed in Table D5. They reflect, to some degree, the opinion of the experts summarized in Appendix E (Table E5). These factors represent the opinion of the authors and are subject to change, depending on input from the users of this evaluation. Note that these weights must be adjusted by the adjustment factor of Figure C2.

Table D5

Current Weighting Factors for Distresses for Eq. (C.5)

Distress Code	Distress	w_i	W_i (%)
1	Misalignment	24	24
2	Corrosion	15	15
3	Settlement	12	12
4	Cavities	12	12
5	Interlock separation	12	12
6	Holes	8	8
7	Dents	6	6
8	Cracks	11	11
			100

APPENDIX E: EXPERT RATINGS FOR CHICAGO FIELD TEST

1. The results of the expert ratings of the nine walls listed in Sec. 4 are presented in this appendix. Figures E1 through E9 show the functional condition index of each expert from the forms in Table 5 for each of eight distresses for each wall. Figure E1 shows the overall wall ratings given by each expert. The average weighting factors tabulated by the experts are listed in Table E1.

2. An overview of the data shows that one expert seemed to exaggerate the wall distresses relative to the ratings of others. This most likely occurred because it was his first exposure to the rating procedure and he may not have been properly briefed on the rating scale. His results have not been included in the averages presented in Part IV.

Table E1

Average Weighting Factors by Experts

Distress	Average Weighting Factor (percent)	
	Retaining Walls	Guide Walls
Misalignment	14	29
Corrosion	18	10
Settlement	13	12
Cavities	11	9
Interlock Separation	15	13
Holes	8	7
Dents	9	9
Cracks	12	10

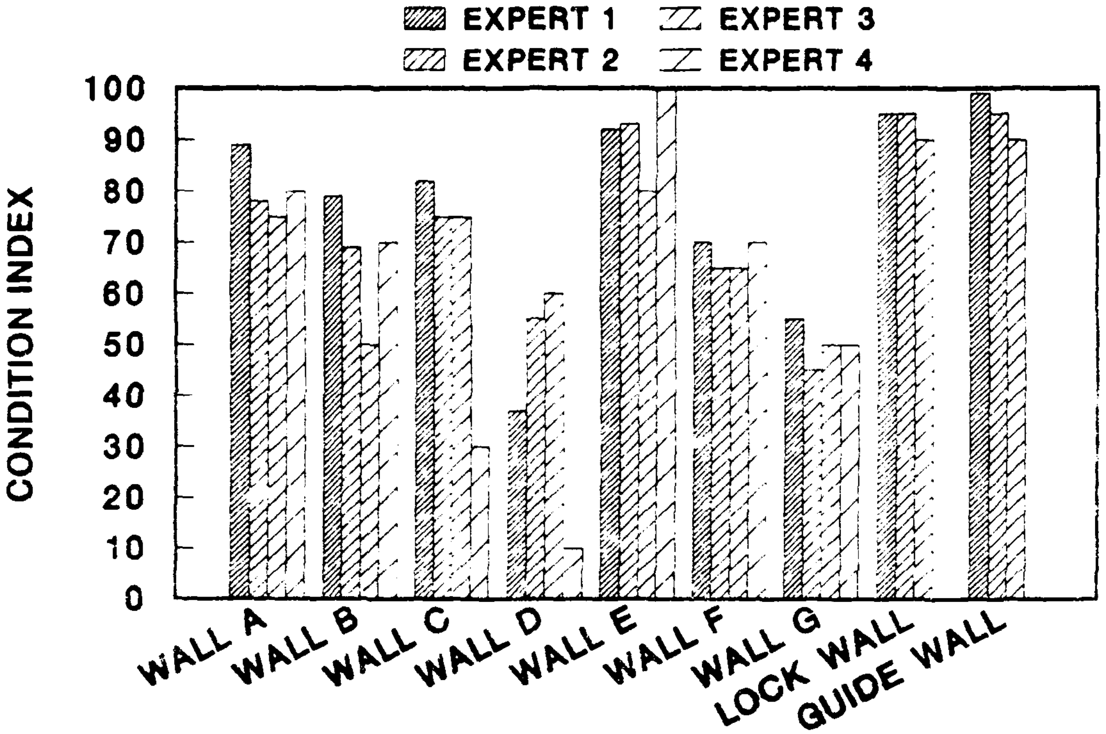


Figure E1. Misalignment condition index by experts

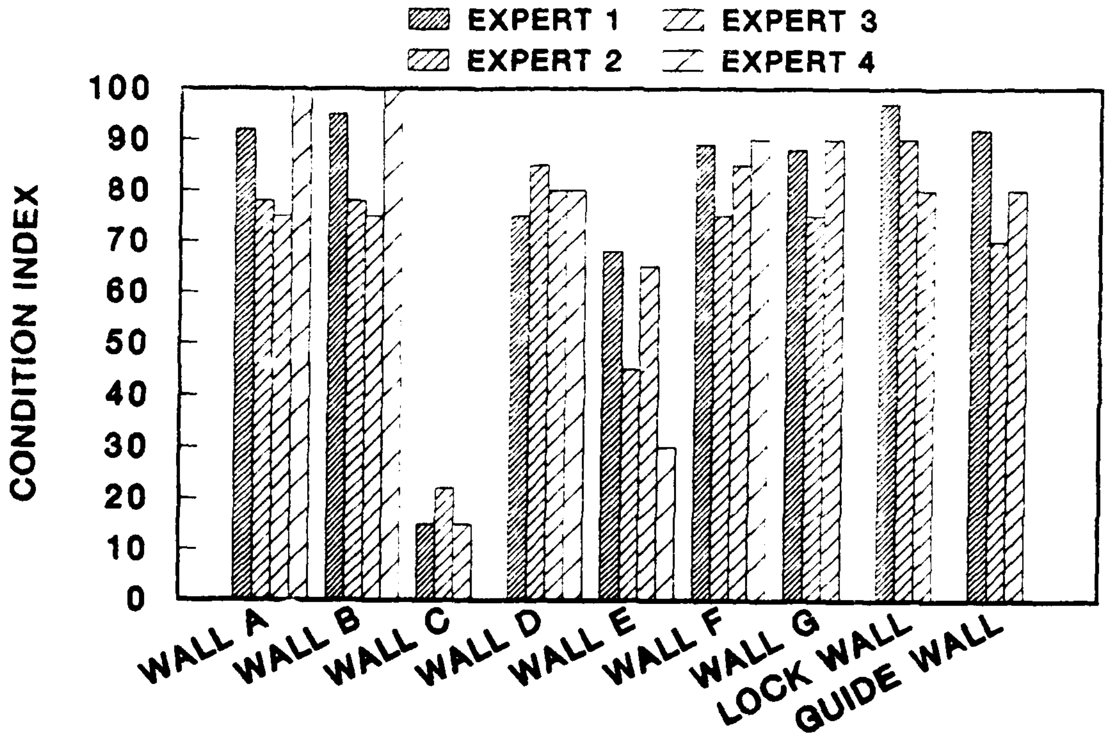


Figure E2. Corrosion condition index by experts

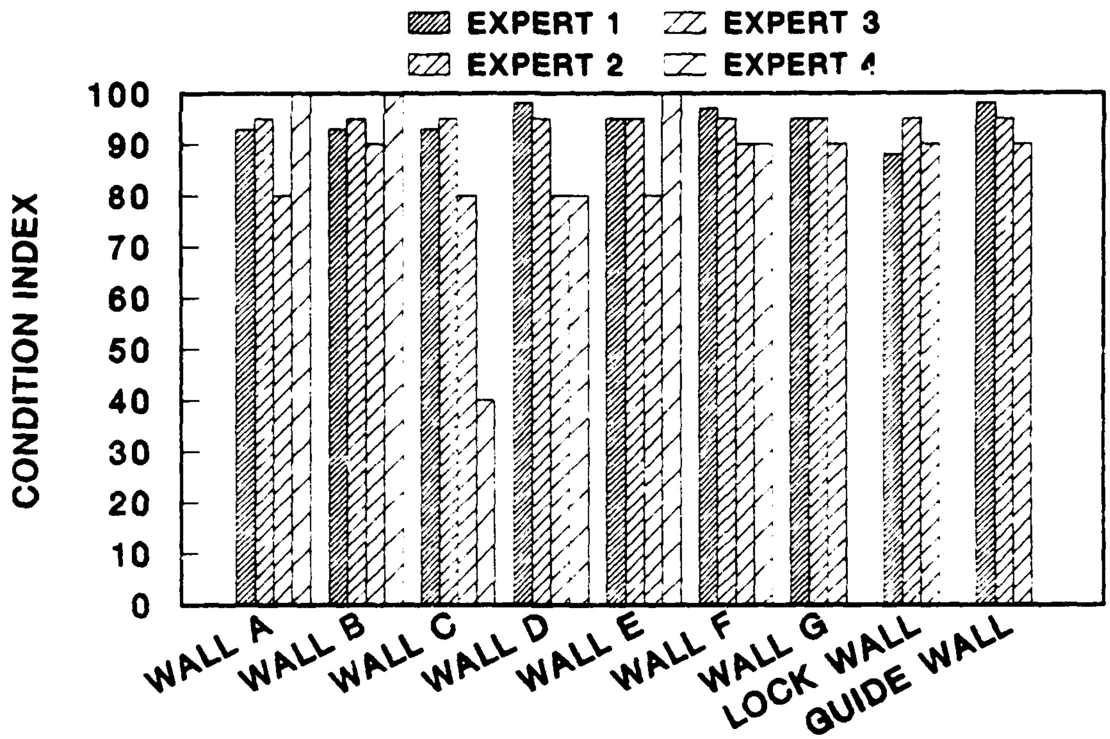


Figure E3. Settlement condition index by experts

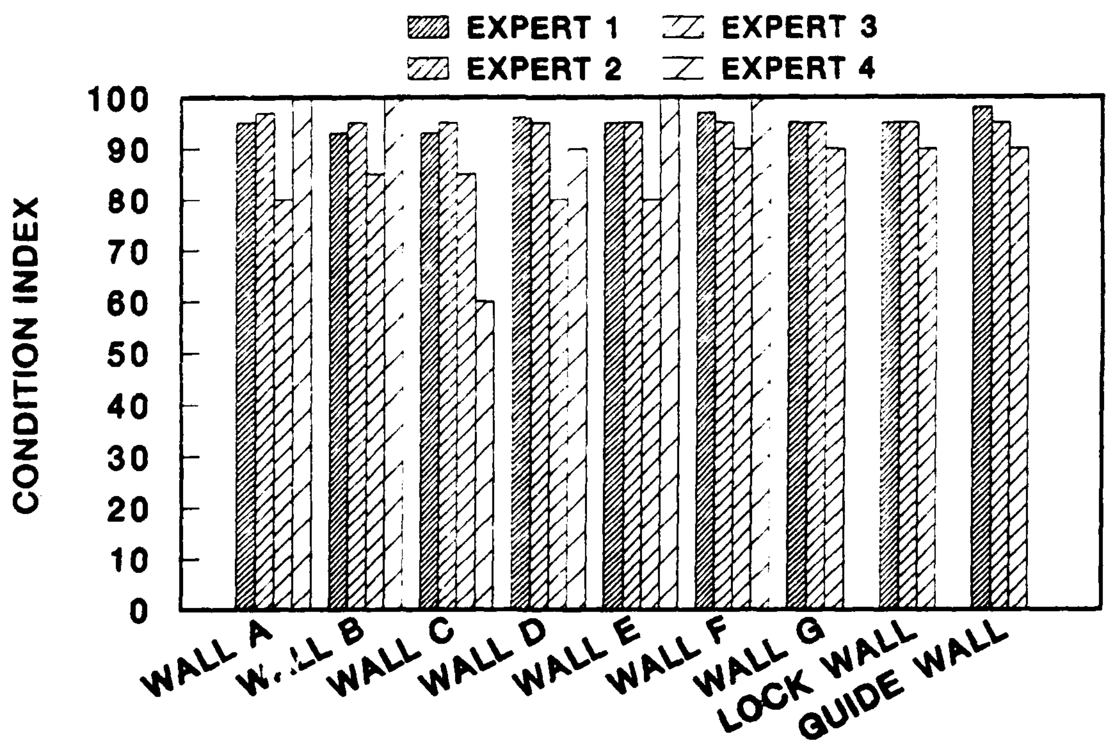


Figure E4. Cavity condition index by experts

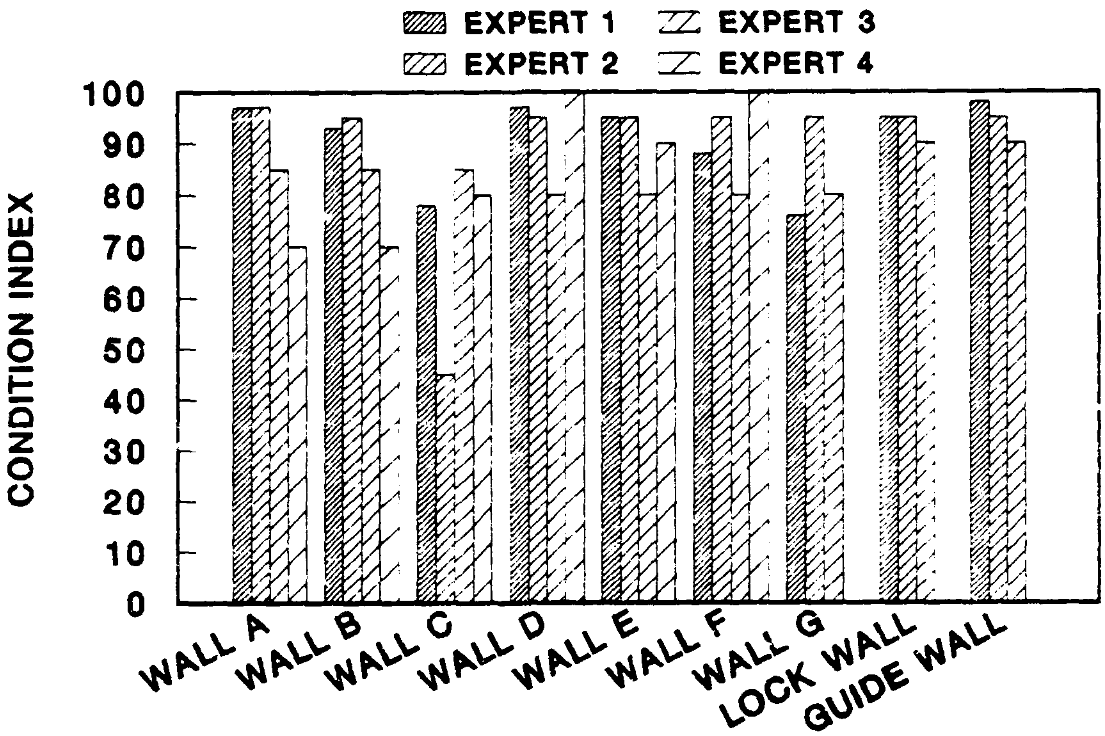


Figure E5. Interlock separation condition index by experts

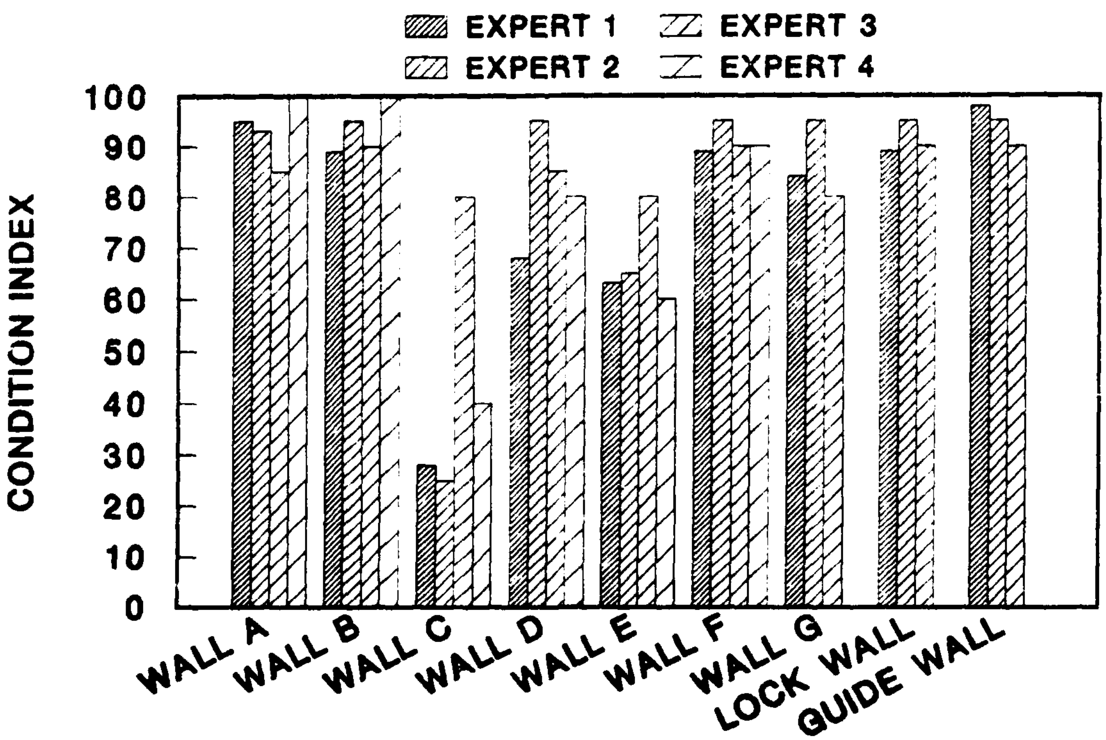


Figure E6. Hole condition index by experts

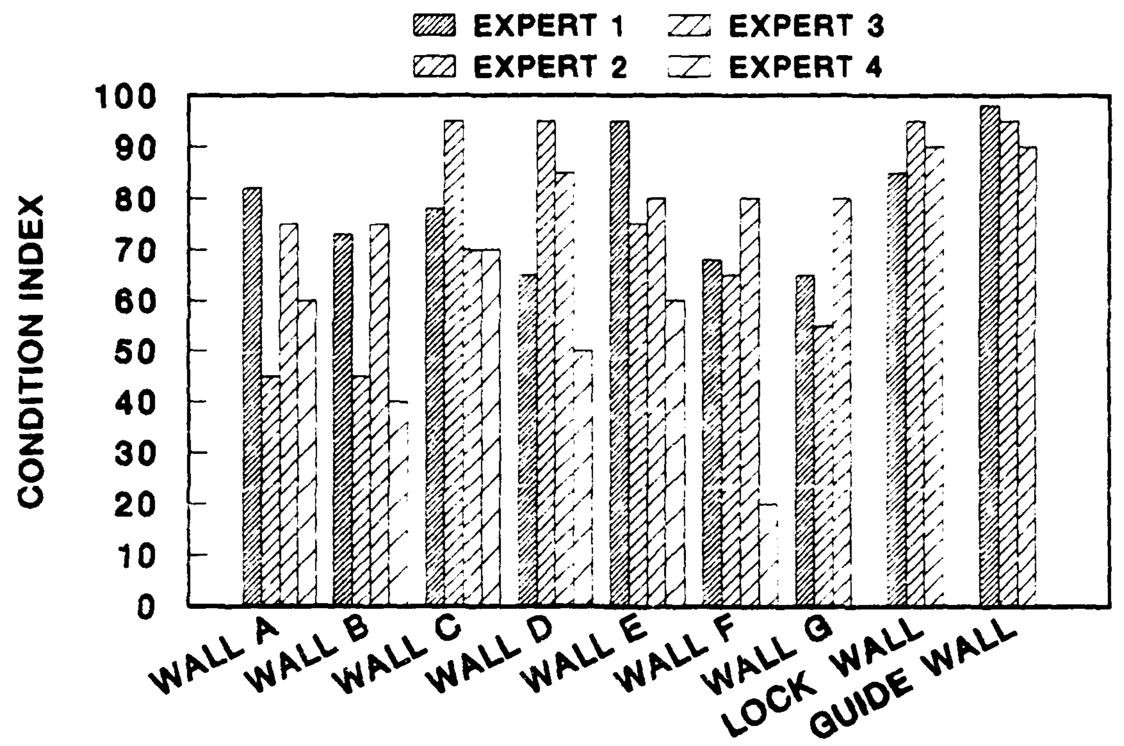


Figure E7. Dent condition index by experts

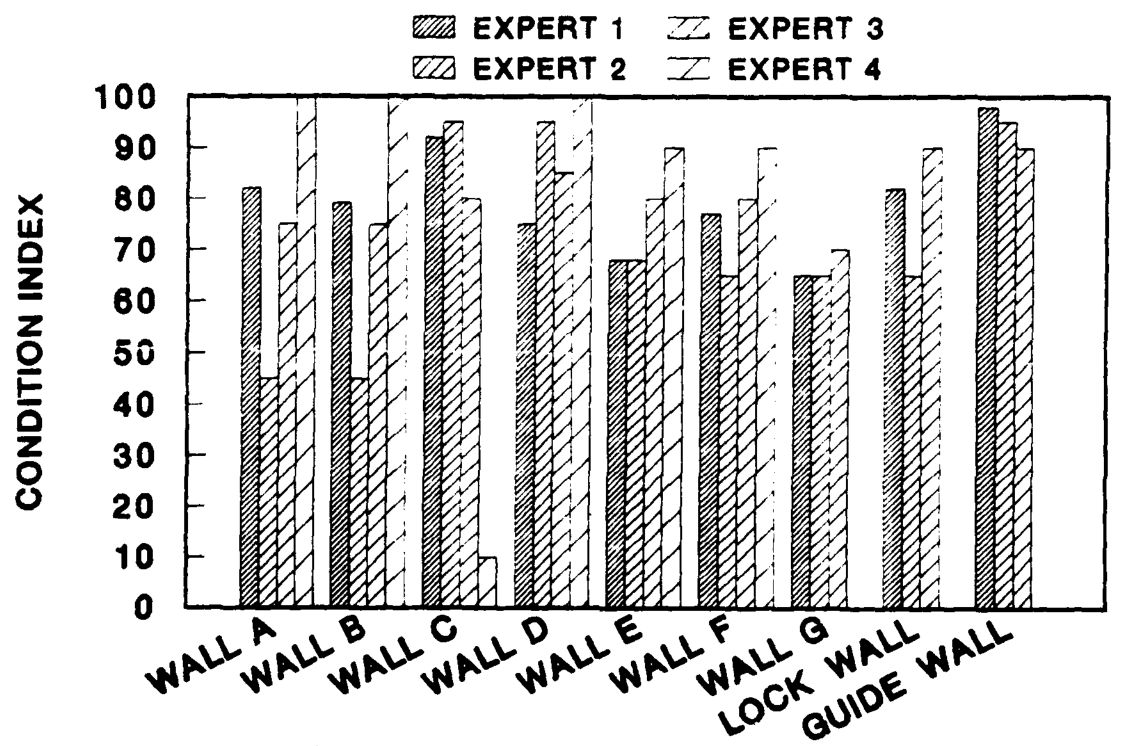


Figure E8. Crack condition index by experts

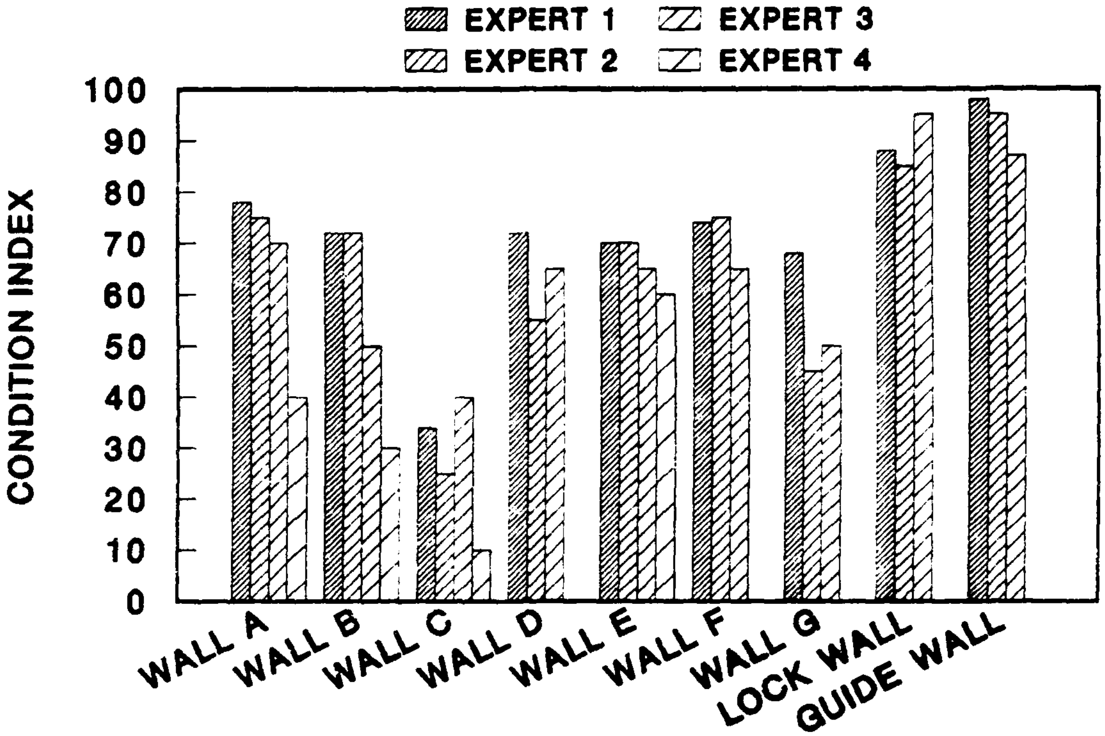


Figure E9. Overall wall condition index by experts